EXPERIMENTAL INVESTIGATION OF TOOL LIFE AND TEMPERATURE DURING HOT MACHINING OF En–24 STEEL

By

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dedicated to my parents

20/7/79

CERTIFICATE

This is to certify that the thesis entitled "EXPERIMENTAL INVESTIGATION OF TOOL LIFE AND TEMPERATURE DURING HOT MACHINING OF En-24 STEEL" by Mr. B.K. Dey is record of work carried out under my supervision and has not been submitted elsewhere for a degree.

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This thesis has been approved for the award of the Degree of Master of Technology (M.Tech.) in accordance with the regulations of the Indian Institute of Technology Kanpur
Dated. 31/7/79

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ABSTRACT

The present report presents the results of an experimental investigation into tool life and temperature relationship in hot machining of En-24 steel with Coromant Carbide inserts of S-4 grade using electric resistance heating.

Prolonged tool wear cutting tests are carried out by varying heating current from 0-200 Amps., covering a speed range of 57 to 166.5 m/min at a constant depth of cut of 2 mm. and a feed rate of 0.15 mm. Cutting forces are measured by using three dimensional octagonal ring dynamometer from continuous force records. Tool temperature is measured by tool-work thermocouple technique. Tool life is obtained by measuring flank wear after suitable cutting time for each test speed and heating current. Surface finish is measured by a Profilometer after each run while the job is on the machine.

Variation of tool life, temperature, cutting forces and surface finish with heating current and cutting speed are presented. Tool-life and temperature relationships are derived. Optimal heating current and cutting speeds are obtained from considerations of tool life and surface finish. The following broad conclusions are drawn :

1. Hot machining by electric resistance heating results in

considerable improvement in tool life, the degree of improvement depends upon the heating current chosen and the optimum cutting speed.

2. An optimum heating current of 150 amps is recommended for machining of En-24 steel at a speed of about 110 to 120 m/min.

LIST OF FIGURES

CHAPTER - 1

INTRODUCTION

1.1 General :

The machinability of a material is given by its adaptability to manufacture by a manufacturing process. It is known that, in general, materials of higher strength exhibit a lower machinability rating. Improved methods of metal removal have been suggested and used for machining of high strength materials. Hot Machining is one such method which has attracted considerable attention and is finding increasing importance in the industries.

Brewer (1) used hot machining for handling machining problems of high strength and heat resistant alloys used in gas turbines, modern aircraft and rockets. Field (2) found that it is difficult to machine, at room temperature, alloys used in aircraft and missile industries. These materials attain tensile strength close to that of the cutting tools due to strain-hardening. Machining at high speeds and large depths of cut causes chatter vibration, tool failure and poor surface finish.

1.2 Principle of Hot Machining :

Hot machining is a machining technique in which the metal removal is carried out at an elevated temperature without the use of any coolant. The increase in temperature reduces the shear strength in the vicinity of the shear zone, resulting in the reduction of the cutting forces so that machining can be carried out satisfactorily.

Hot machining has two main functions in the machining of high strength materials. These are :

1. To facilitate machining of components which would otherwise necessitate some additional expensive manufacturing process.

2. To improve the production and machining economics of the materials.

1.3 Work-piece Heating Techniques :

The successful application of hot machining depends on proper selection of a suitable heating technique. The main requirements of a suitable heating technique are as follows :

1. The heating should be confined as much as possible to the shear zone.

2. A high specific heat input is required in order

to attain a high temperature of workpiece. The temperature should not be so high as to cause thermal damage to the workpiece.

3. The heating method should be cheap and easy to install.

4. The method employed should not be dangerous to the operator.

5. Temperature control should be quick and easy.

6. The method should be applicable to production type machinery under workshop conditions, allowing for quick machining set up.

Several heating techniques have been employed in the investigations (3, 4, 5) of hot machining. Barrow (3) has compared the various heating techniques in terms of its advantages and disadvantages and has concluded that electric resistance is a suitable technique for heating the workpiece.

In the present investigation of hot machining, electric resistance heating has been used for heating the workpiece.

CHAPTER - 2

LITERATURE SURVEY

Heating the workpiece to improve machinability is not a recent technique. As early as 1941, hot billets of steel were sawed at Krupps Steel Works in Germany. No systematic research was undertaken until in 1957 it was initiated by Cincinatti Milling Machine Company. Between 1941 to 1951 some reports (6,7,8) appeared in literature. All of them reported decrease in cutting force and improvement in tool life.

2.1 Tool Life in Hot Machining :

Studies regarding tool life during hot machining have been carried out by many investigators. Pentland et.al.(4) found that tool life improved by five times and twenty times than that obtained in conventional machining when cutting AM 350 (400 BHN) and AISI 4340 (600 BHN) steels respectively, at elevated temperature upto 900°F with carbide cutting tools. Armstrong et al (7) achieved tenfold increase in tool life when cutting austenitic stainless steel at 400°F. However when machined at 1500°F the tool life was found to be one fifth of its value obtained with conventional machining. They found that there is an optimum

temperature for which tool life will be a maximum while machining AISI 3145 steel. Barrow (3) found that at a constant cutting velocity there is an optimum value of heating current for maximum tool life. He concluded that a heating current in the range of 75 to 175 amperes results in an increase in tool life of at least 200 percent. The optimum depends upon the relative importance of the effects of increasing chip-tool interface temperature and the decreasing cutting force on tool wear. Barrow (9) reported improvements in tool life for En 23 and RS 141 steels over a wide range of cutting conditions. He found that for a given heat input there exists an optimum speed and feed for maximum tool life. However, he found the rate of crater wear to increase with heating currents even though the rate of flank wear decreases in hot machining. Pal and Basu (10) investigated hot machining of austenitic manganese steel by shaping and found that the tool life depends upon the workpiece temperature and relative cutting speed. Lo et al (11) made a theoritical investigation using statistical technique for predicting the fool life with four variables of speed, feed, depth of cut and direct current.

2.1 Investigation of Tool Temperature :

Schallbroch et al (12) carried out a series of experiments in conventional machining and suggested the following relationship for tool life T and temperature θ :

$$\theta \, T^{1/m_1} = C_t$$

where m_1 and C_t are constants for a given tool material. For dry turning of structural steel with 18-4-1 H.S.S. tool with 2.5% Cobalt, they found that C = 1380 and m_1 = 11.5.

Karbacher and Merchant (8) carried out experiments in hot machining to study the cutting parameters on tool life. They established a relationship between the tool life T, temperature θ and the thrust force F_t for mild steel

$$F_t \, \theta \, T^x = C_1$$

where C_1 = characteristic constant = 5,30,000

x = 1/20

For conventional machining, Boothroyd and Eagle (13) found an increase in the mean tool temperature at the work-tool interface with increasing wear land. Recently,

Groover et al (14) have proposed a mathematical model for explaining tool wear and temperature. Kainth and Chaturvedi (15) made a theoritical investigation to predict temperature for the case of orthogonal machining.

No investigation has been carried out to relate the temperature θ with tool life T in the case of hot machining. In the present investigation an attempt has been made to relate tool life with temperature .

CHAPTER - 3

EXPERIMENTAL SET UP AND PROCEDURE

3.1 Experimental Set Up :

Tool wear tests are carried out by machining En-24 steel on H.M.T LB-17 lathe, with Coromant Carbide tips at a depth of cut of 2 mm. and a feed of 0.15 mm/rev. The cutting speed is **varied** between 57 to 166.5 m/min. at heating currents varying from 0-300 amps.

Hot machining experiments are carried out on the experimental set-up designed and fabricated by Chaudhary (16) and Sachdeva (17). A close-up of the set-up is shown in Fig. 1. The schematic diagram of the system is shown in Fig. 2.

3.1.1 Workpiece Heating Technique :

Electric resistance heating technique is used for heating the workpiece. A step down transformer having specifications 220/5 volts, 50 HZ, 3 KVA rating is used for supplying upto 300 amperes alternating current. To get various heating currents, the input to the transformer is varied by using a variac having specification 220 volts, 15 amperes.

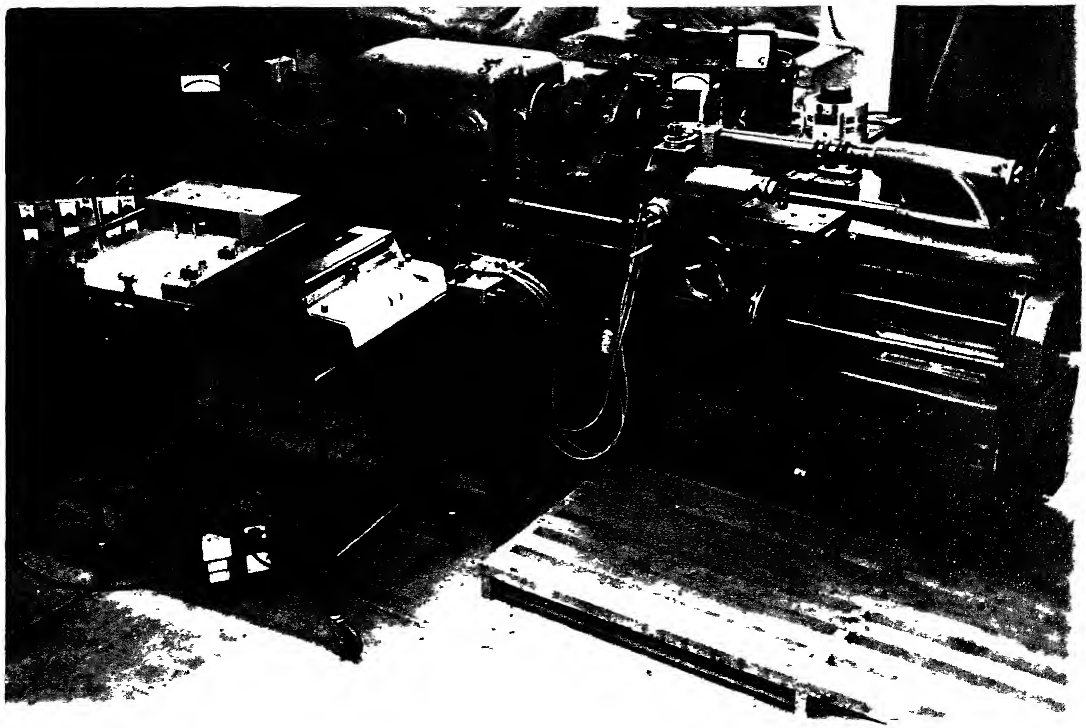

FIG. 1 : CLOSE-UP OF EXPERIMENTAL SET-UP

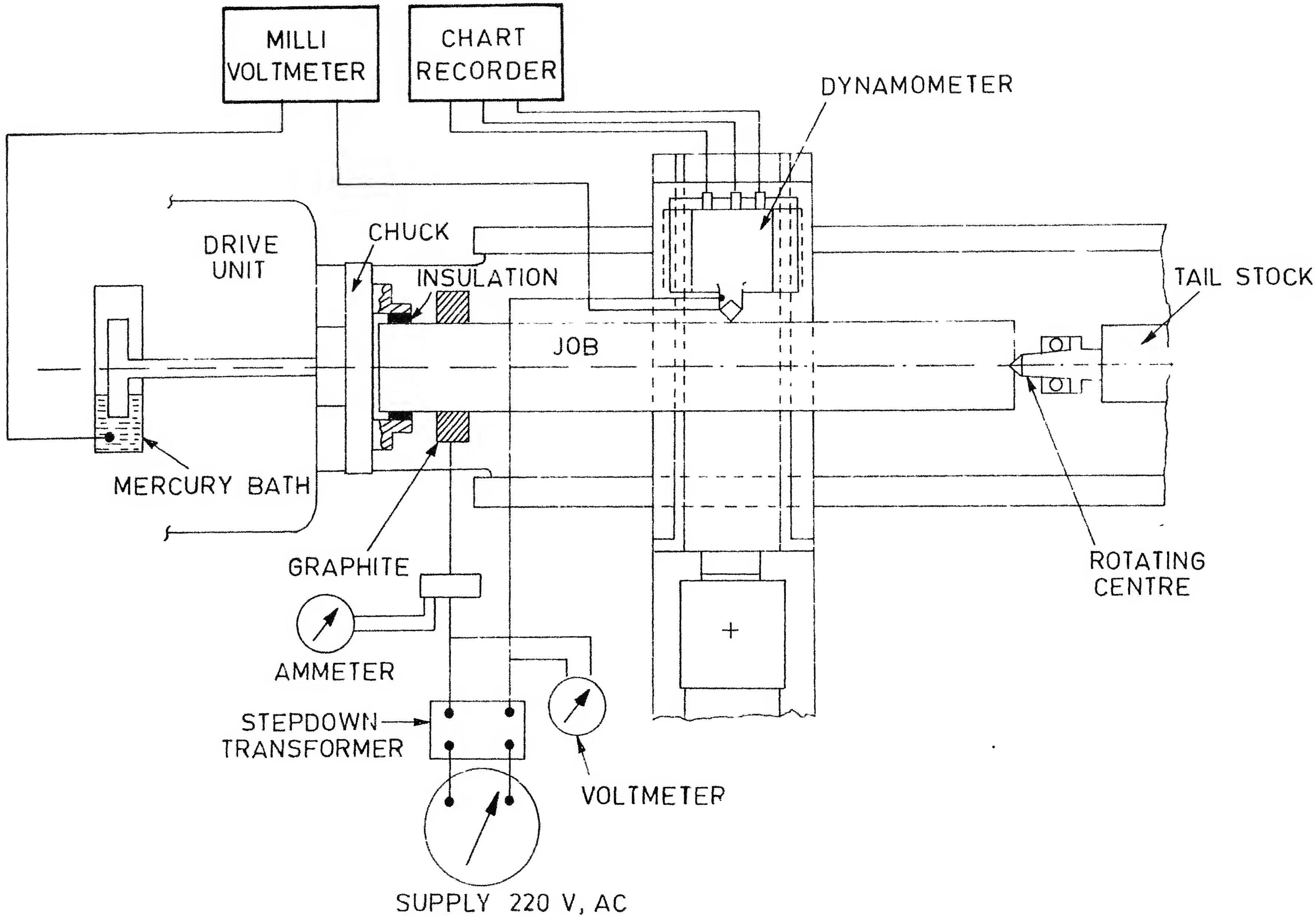

FIG. 2 SCHEMATIC VIEW OF THE EXPERIMENTAL SET-UP.

The high alternating current, low voltage output from the step down transformer is carried by cables having 600 amperes carrying capacity, to copper-graphite brushes. The copper-graphite brushes are mounted on a steady-rest and are kept apart at 120 degrees to ensure contact with the workpiece during rotation. The tool is connected to the negative terminal and it is insulated from the dynamometer.

A current transformer having ratio of 1000/5, is used for measuring the current flowing through the cables. The secondary of the transformer is connected to an ammeter of range 0-5 ampere. A voltmeter of 0-5 volt range is connected across the output of the step-down transformer to measure the voltage at which the current is being supplied.

3.1.2 Three Dimensional Lathe-Tool Dynamometer :

A three-dimensional dynamometer is used for measuring forces upto 400 kgs, 200 kgs. and 100 kgs. in the tangential, feed and radial directions respectively as shown in Fig. 3. The dynamometer consists of two extended octagonal rings. Twenty four strain gauges, each of 100 ohms nominal resistance and 2.82 gauge factor, are cemented at various positions on the dynamometer. The

F_c: TANGENTIAL CUTTING FORCE
F_f: FEED FORCE
F_r: RADIAL FORCE

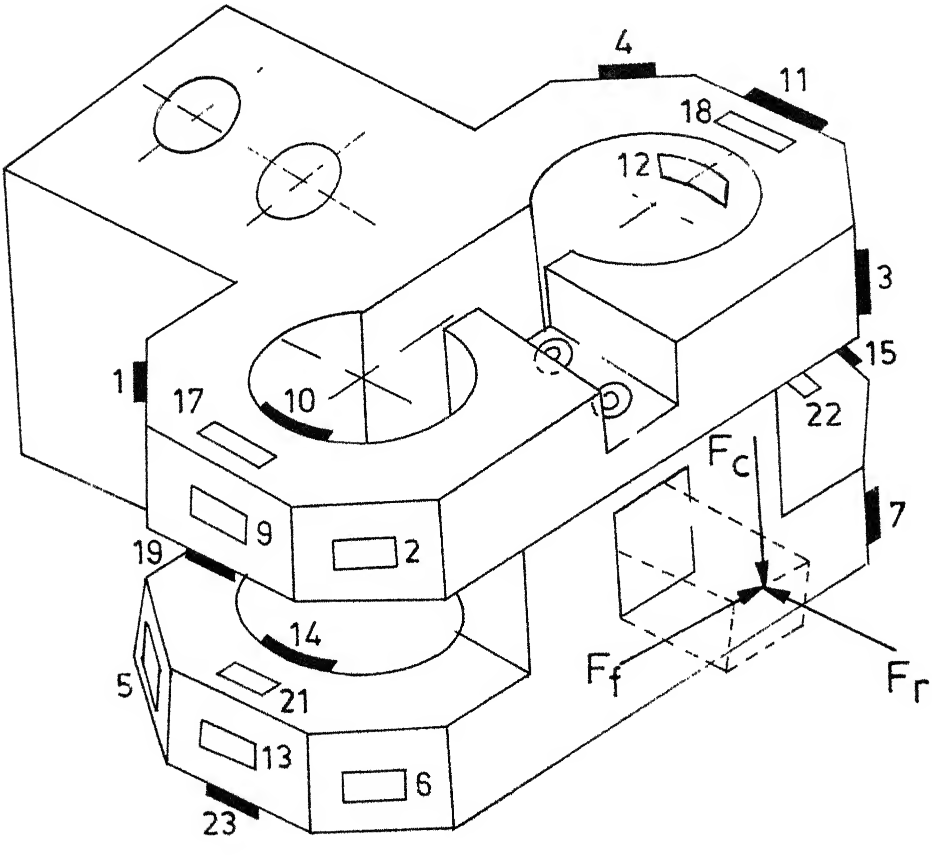

FIG. 3 THREE COMPONENT LATHE TOOL DYNAMOMETER.

gauges are connected to form Wheatstone Bridge circuits, so as to give minimum cross-sensitivity between the three force components. The connections of the gauges for measuring forces in the three directions are shown in Fig. 4.

The dynamometer is enclosed in a brass box to ensure protection from chips during cutting operation. The dynamometer is bolted on a holding platform and mounted on the compound slide of the lathe.

The dynamometer is calibrated by suitably mounting it on a loading frame as shown in Fig. 5. The lever arm ratio for calibration is kept at 4:1 in all the three directions. A dummy tool holder is fitted in the dynamometer for the purpose of loading at appropriate position. The lever arm rests on the dummy tool-holder at a distance of 25 cm. from the fixed end and weights are hung at a distance of 100 cm.

Fig.6 shows the calibration curve for the tangential cutting force, F_c and Fig. 7 shows the calibration curve for the feed force F_f and radial force F_r. The dynamometer has cross-sensitivity less than one percent in all the three directions.

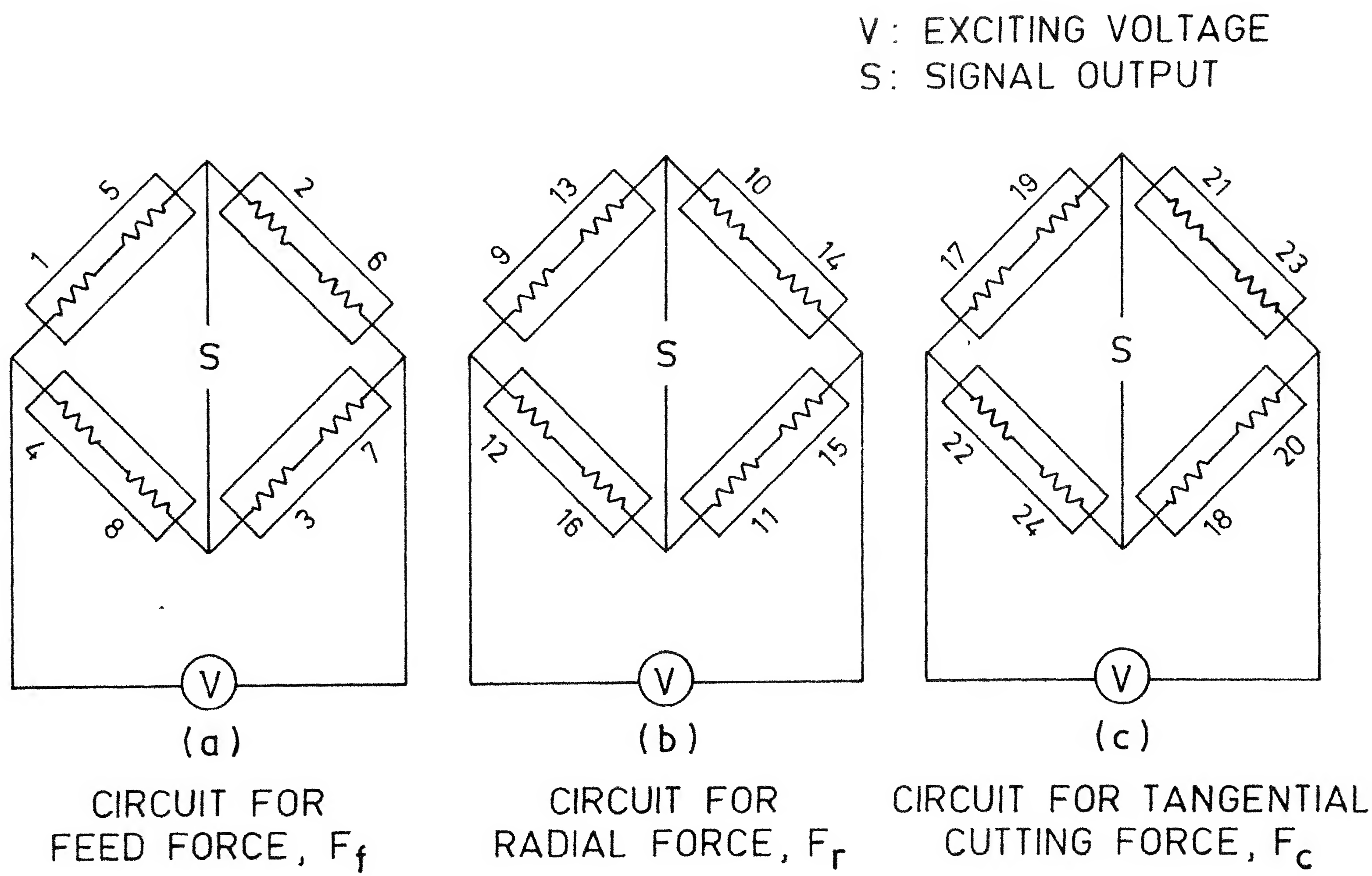

FIG. 4 WHEATSTONE BRIDGE CIRCUIT FOR THREE FORCE COMPONENTS.

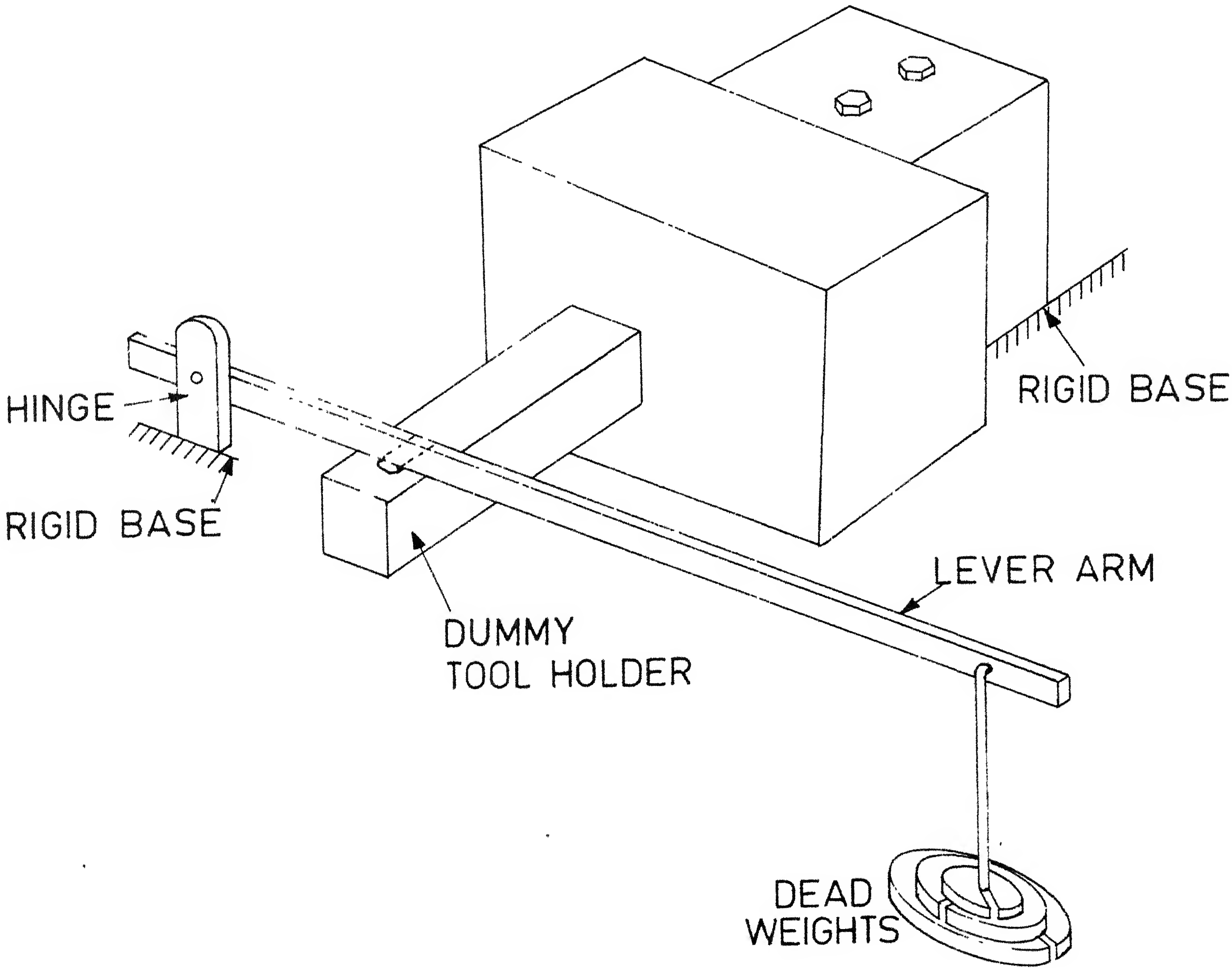

FIG. 5 SET-UP FOR CALIBRATION OF DYNAMOMETER

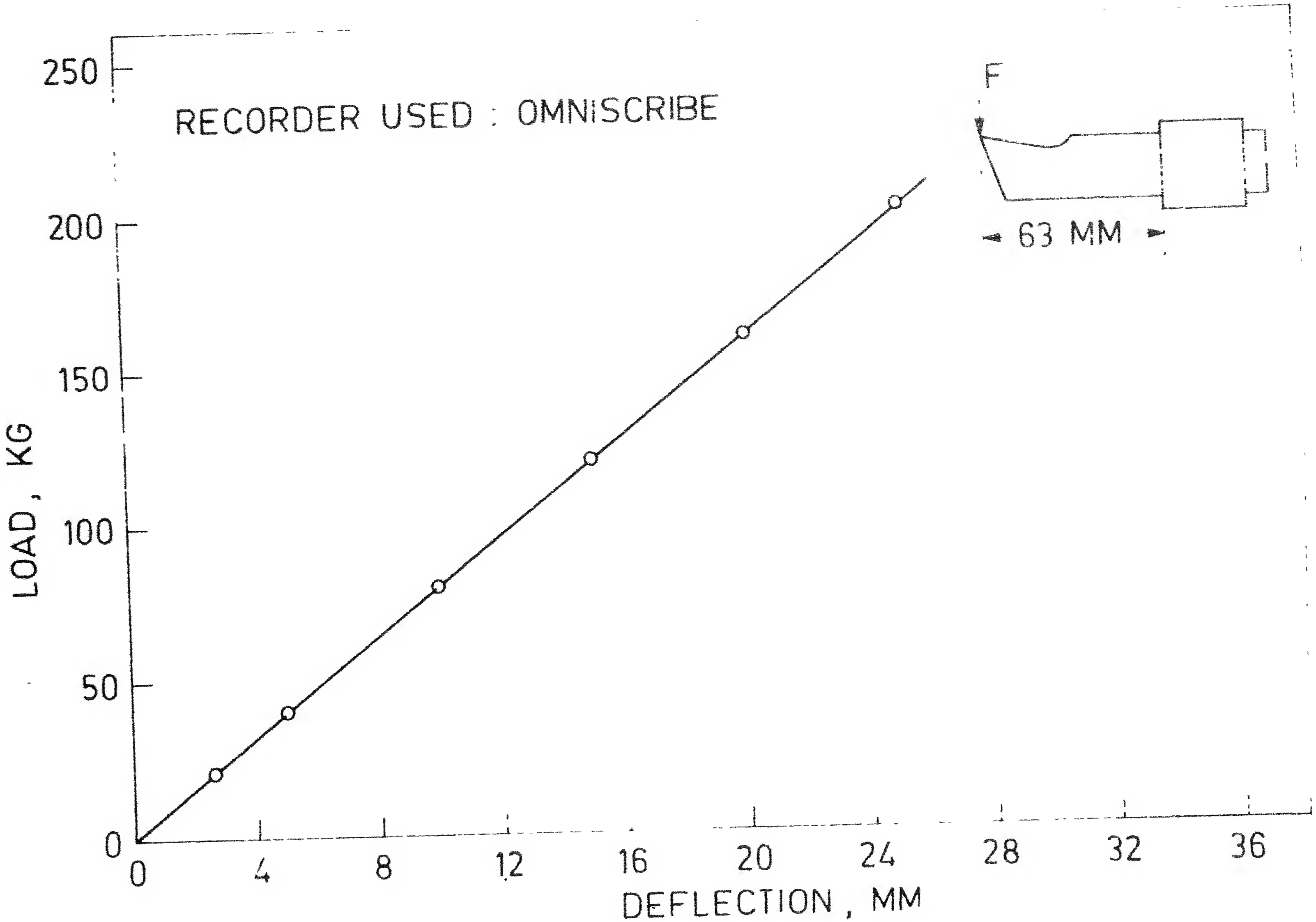

FIG. 6 CALIBRATION CURVE FOR TANGENTIAL CUTTING FORCE F_c, AT SENSITIVITY 1 MILLIVOLT = 25 CM

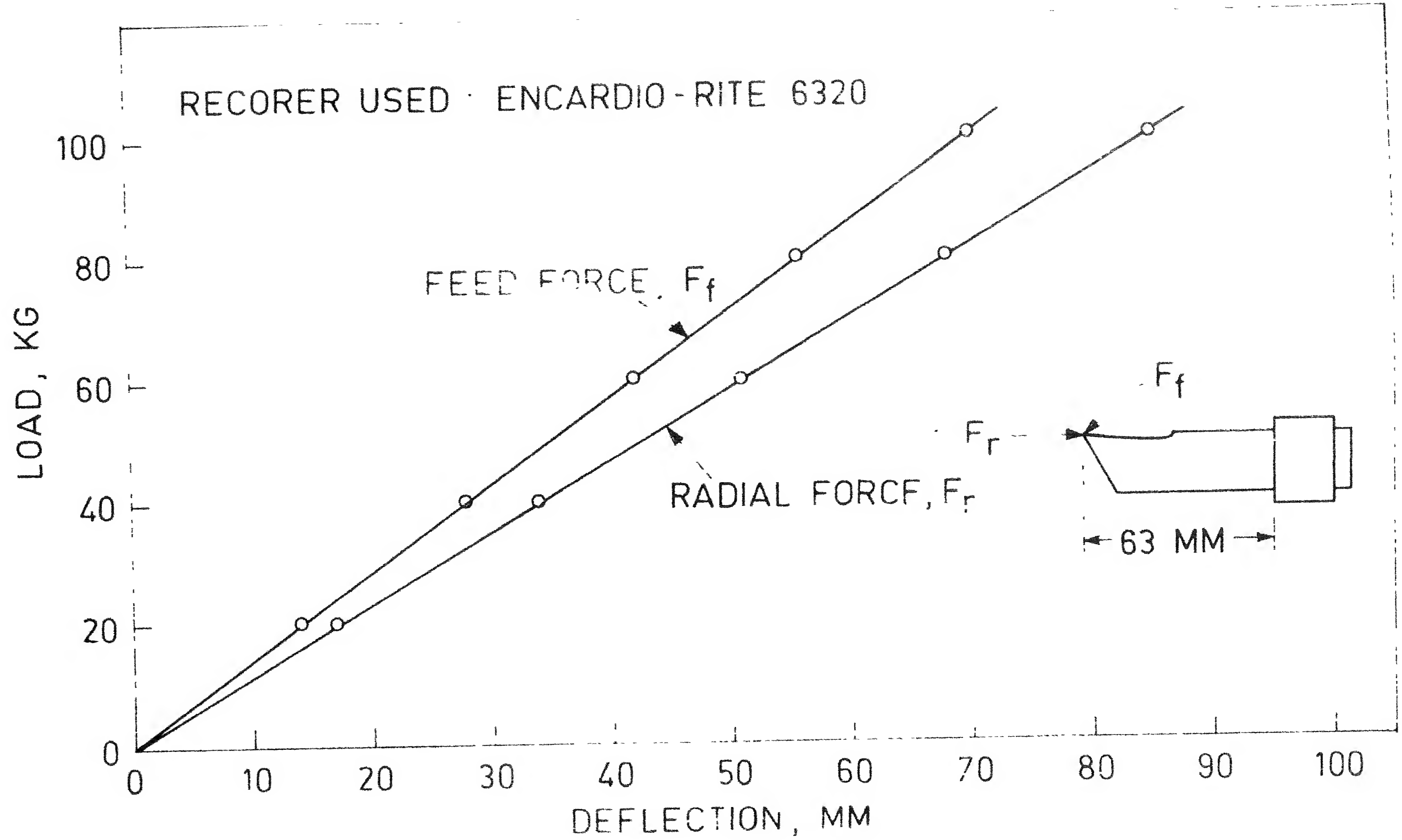

FIG. 7 CALIBRATION CURVE FOR FEED FORCE AND RADIAL FORCE AT SENSITIVITY 0.1 MILLIVOLT = 1 CM.

3.1.3 Set-Up for Temperature Measurement:

The temperature at the tool tip is measured with the help of a tool-workpiece thermocouple. The workpiece and the tool are properly insulated from the lathe. In this method of temperature measurement, the tool-work contact area serves as a hot junction in a thermo-electric circuit and the emf generated is proportional to its temperature. A copper disc fixed at the end of a rod secured to the workpiece, is kept at room temperature and acts as a cold junction. A mercury bath is used to make electrical contact with the rotating copper disc. Ordinary copper wires connect the mercury bath and the tool to a milli volt meter of range 0-10 mV. The emf generated is read directly on the milli-voltmeter. The temperature is read from the calibration curve shown in Fig. 8.

3.1.4 Intrumentation used for Measurements:

The cutting force components are recorded simultaneously on strip chart recorders. The tangential cutting force F_c is recorded on a strip chart recorder of the following specifications: Make-Omniscribe; Sensitivity- 10 to 0.001 volts full scale deflection and chart speed-1 to 20 cm min. The tangential cutting force is recorded at a sensitivity of 1 mv full scale deflection. The feed force, F_f, is recorded on a dual

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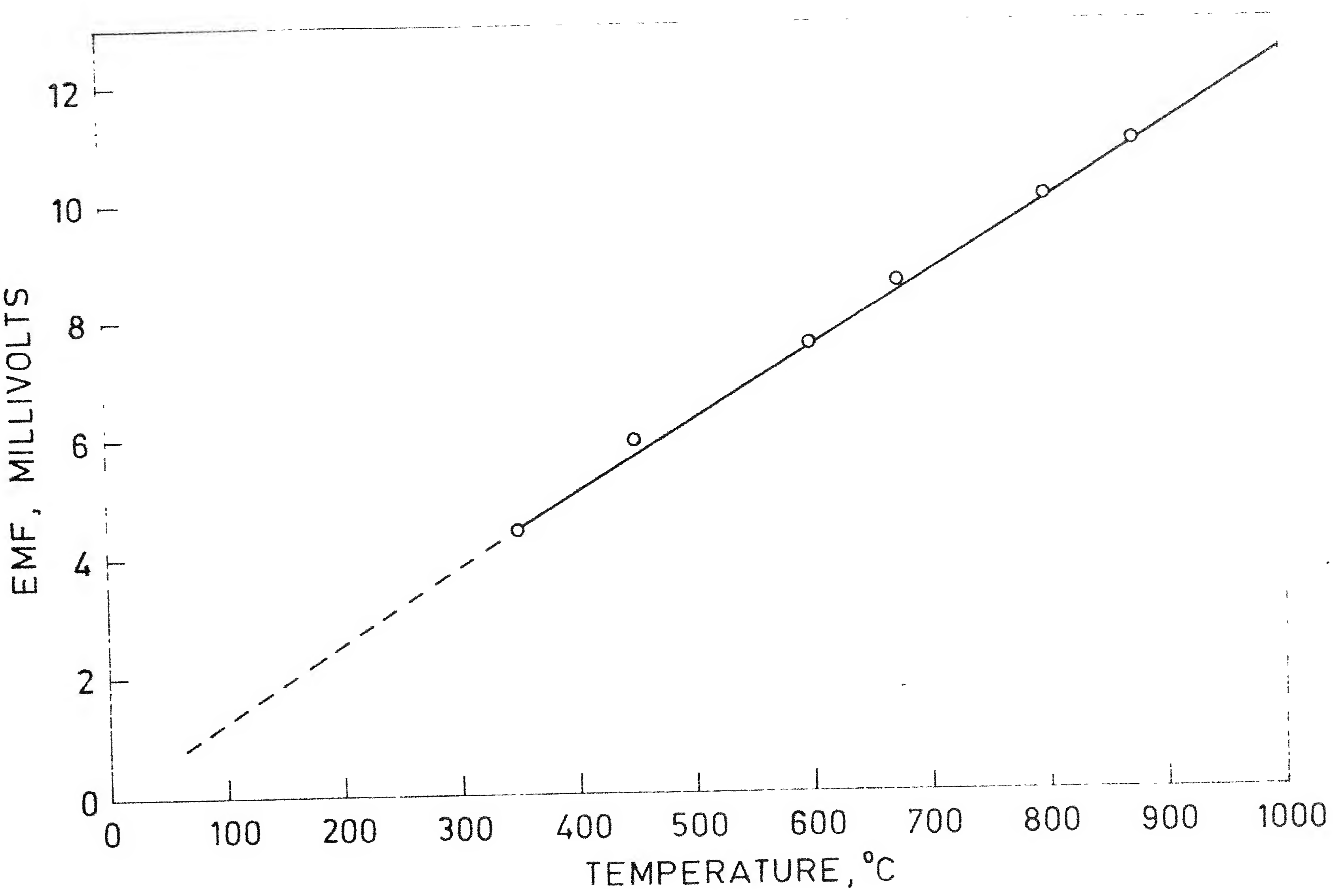

FIG. 8 TEMPERATURE CALIBRATION CURVE FOR EN-24 STEEL-WC THERMOCOUPLE

channel recorder of the following specifications. Make-Encardio-rite-6320; sensitivity-10 to 0.0001 volts per cm. and chart speed-1 to 25 mm/sec. The feed force is recorded at a sensitivity 0.1 mV per cm.

Length of flank wear was measured on a tool-room microscope of least count of 0.002 mm.

Surface finish is measured with the help of a 'Profilometer'.

3.2 Experimental Procedure :

The workpiece of En-24 steel of length 900 mm. is initially turned to a diameter of 73 mm. Hot machining tests are carried out at a constant depth of cut of 2 mm and a feed of 0.15 mm/rev. The Coromant Carbide 194.4-1623-S-4 throwaway tips are used.

In order to study the effect of current and speed on cutting forces and surface finish, experiments are carried out using a new tip thus providing a sharp cutting edge for each test. The experiments are carried out for heating currents of 0 to 300 amperes at different cutting speeds in the range of 57 to 166.5 m/min.

Tool wear tests are carried out at heating currents of 0, 100, 150, 200 amperes. The cutting speed is varied

in the range of 70 to 140 m/min. The heating current is switched on immediately after the engagement of the tool with the workpiece and turned off just before the disengagement of the tool to avoid sparking and consequent damage to the tool tip. The flank wear is measured at suitable intervals of cutting period by removing the carbide tip until the flank land exceeds 0.25 mm which is the criterion fixed for tool life. The cutting forces are continuously recorded while temperature at the tool-tip is read from milli-volt-meter for each test. The surface finish is measured with a Profilometer at the end of each cut while the job is on the machine.

CHAPTER - 4

EXPERIMENTAL RESULTS AND DISCUSSIONS

Results of experimental investigation detailed in the previous chapter are presented and discussed here. The results hold good for hot machining of En-24 steel with Coromant Carbide throwaway tips 194.4-1623-S-4 grade with tool geometry (0, 6, 11, 11, 15, 15, 1.2), for depth of cut of 2 mm and feed of 0.15 mm/rev.

4.1 Variation of Cutting Forces and Surface Roughness with Heating Current :

Figs. 9 to 12 show the variation of cutting forces at various heating currents and different cutting speeds using a 'sharp' cutting edge for each test. Figs. 9 and 10 show that the decrease in the tangential cutting force is between 15 to 22 percent while the decrease in feed force is between 10 to 17 percent with heating current upto 300 amps. for a constant cutting speed. The decrease in the cutting forces is due to the reduction in the yield shear strength of the material with increase in the heating current. Figs. 11 and 12 show the decrease in the cutting forces with increase in cutting speed at various heating currents. Barrow (3) also found the reduction of

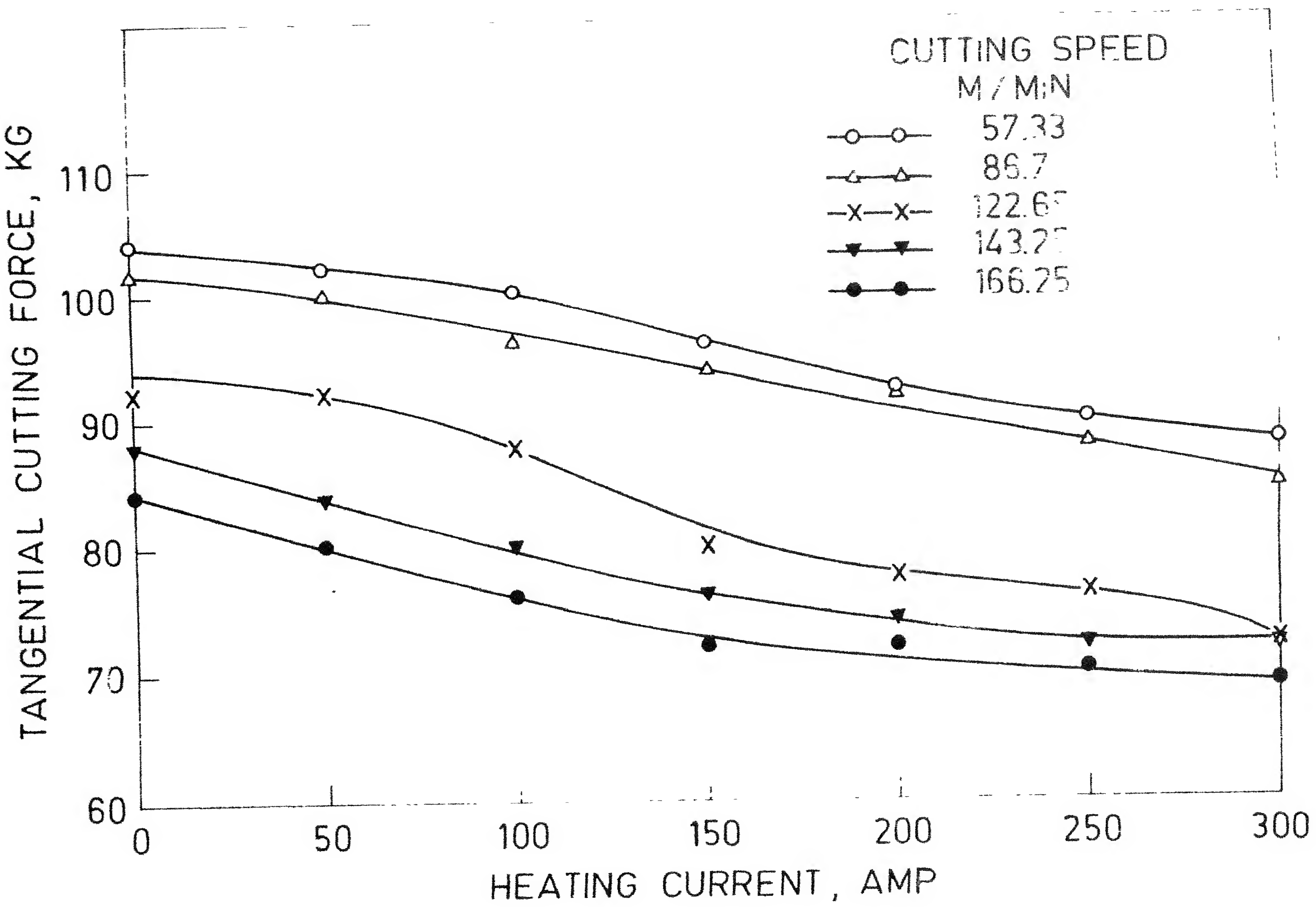

FIG. 9 TANGENTIAL CUTTING FORCE VERSUS HEATING CURRENT AT VARIOUS CUTTING SPEEDS

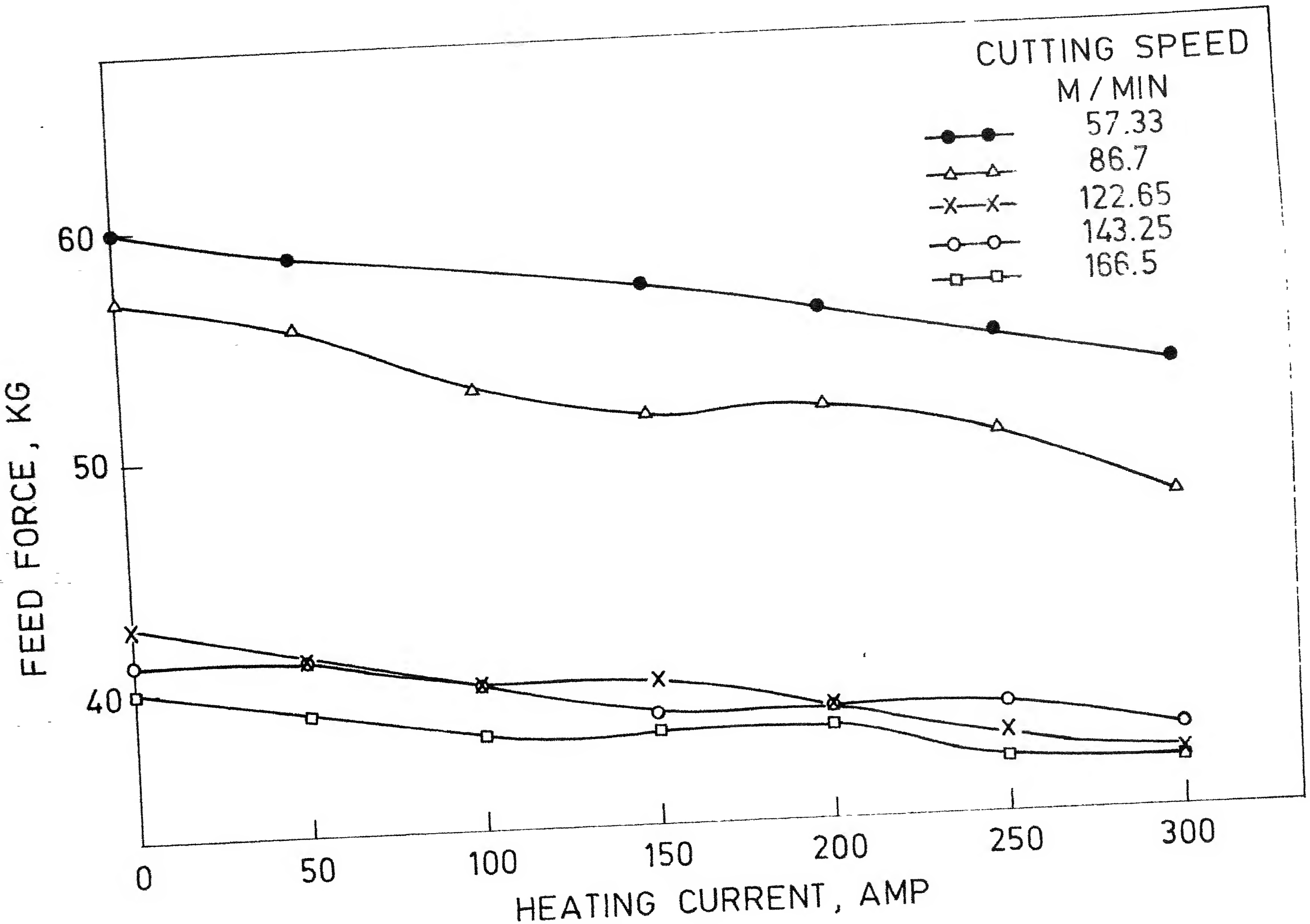

FIG. 10 FEED FORCE VESUS HEATING CURRENT AT VARIOUS CUTTING SPEEDS.

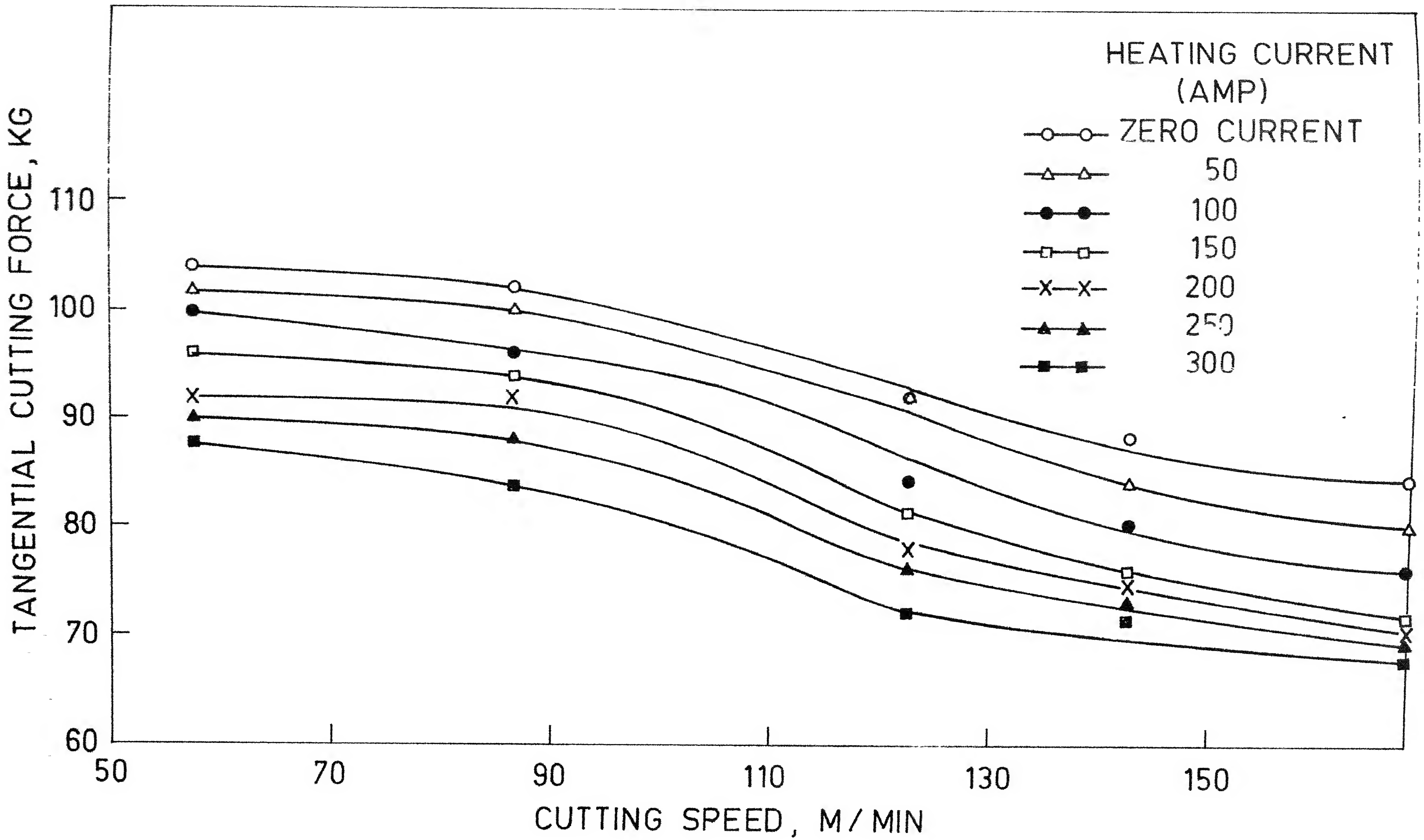

FIG. 11 TANGENTIAL CTTING FORCE VERSUS CUTTING SPEED AT VARIOUS HEATING CURRENT.

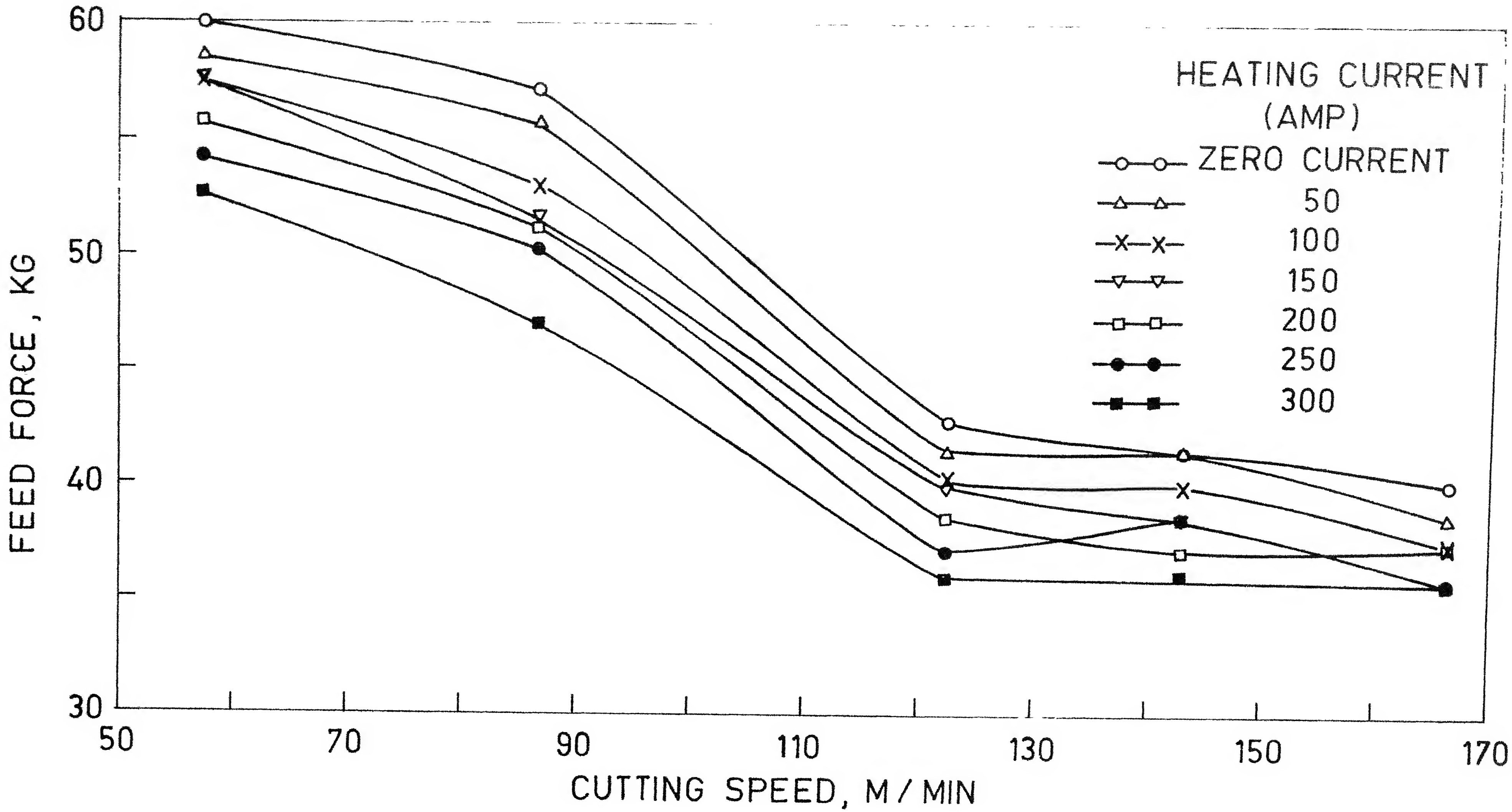

FIG. 12 FEED FORCE VERSUS CUTTING SPEED AT VARIOUS HEATING CURRENT

the cutting forces with heating current at constant cutting speeds.

Fig.-13 shows the variation of surface roughness with heating current for different velocities. The surface roughness decreases with increase in heating current. At lower speed (57.3 m/min) the improvement is considerable due to the disappearance of the buildup edge at higher heating currents. At higher speeds the surface finish soon approaches optimum value showing little improvements with further increase in heating current.

4.2 Variation of Tool Life with Current and Cutting Speed :

Figs. 14 to 17 show the variation of length of flank wear with time at constant current and different cutting speeds. It was not considered necessary to carry out tests upto the conditions of catastrophic wear. It is found that the length of flank wear increases linearly with time for a constant cutting speed in the range investigated. The length of flank wear land of 0.25 to 0.4 mm is generally used as the tool life criterion for carbide tool (9). In this investigation the length of flank wear land of 0.25 mm is selected as the tool life criterion. For this tool life criterion, the tool life for different speeds at a particular heating current

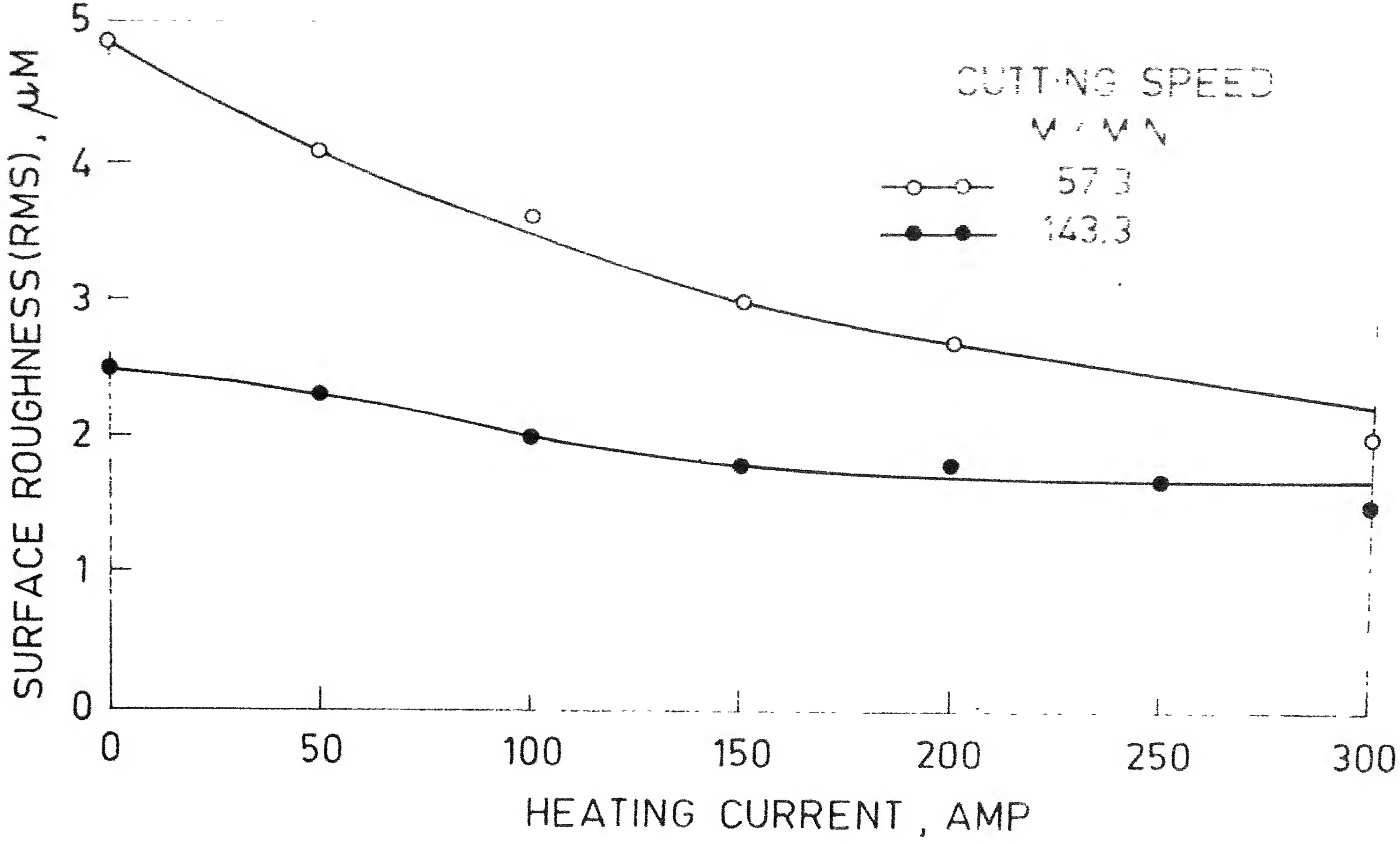

FIG. 13 SURFACE ROUGHNESS VERSUS HEATING CURRENT

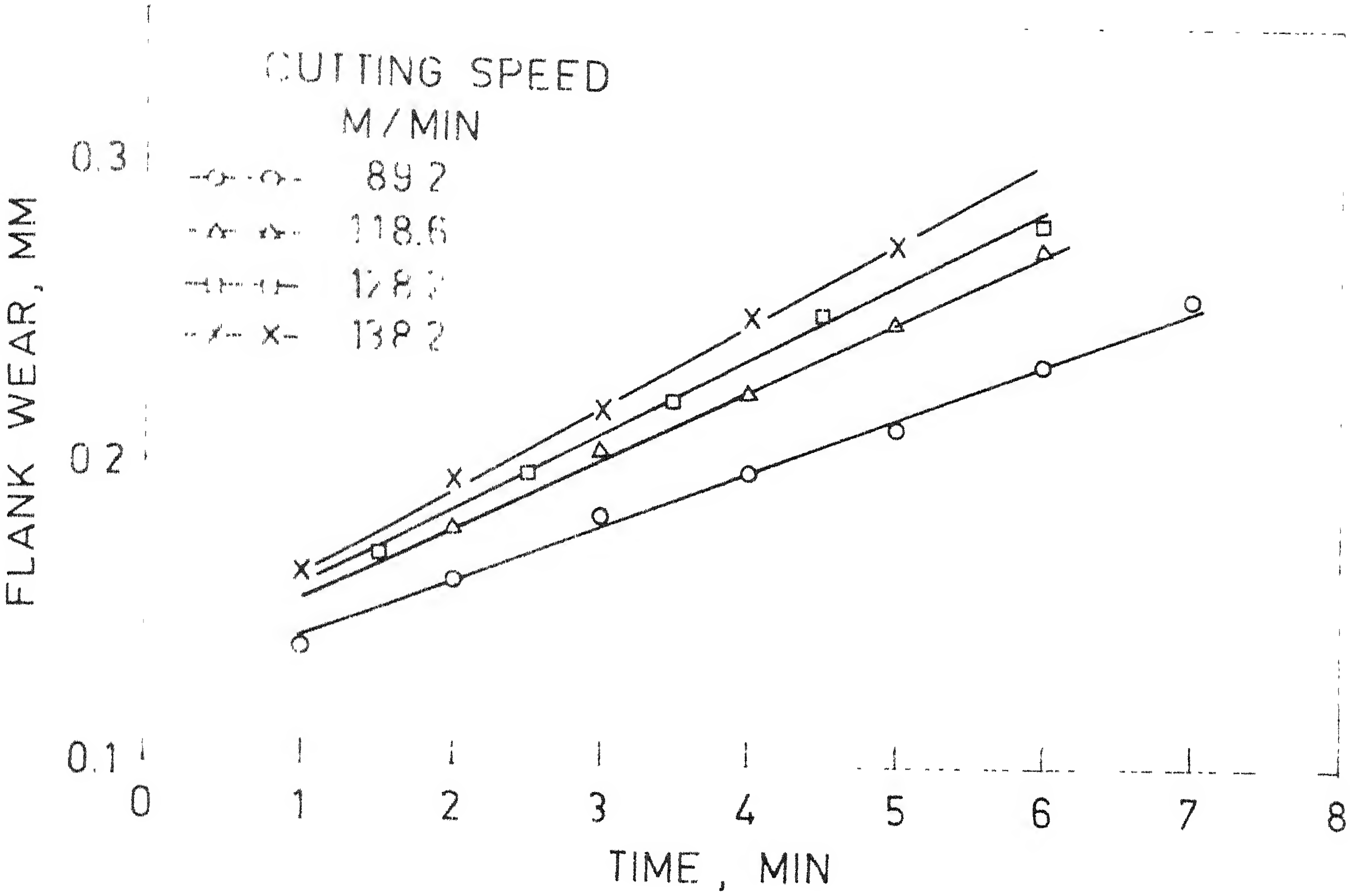

FIG. 14 VARIATION OF FLANK WEAR WITH TIME AT ZERO CURRENT.

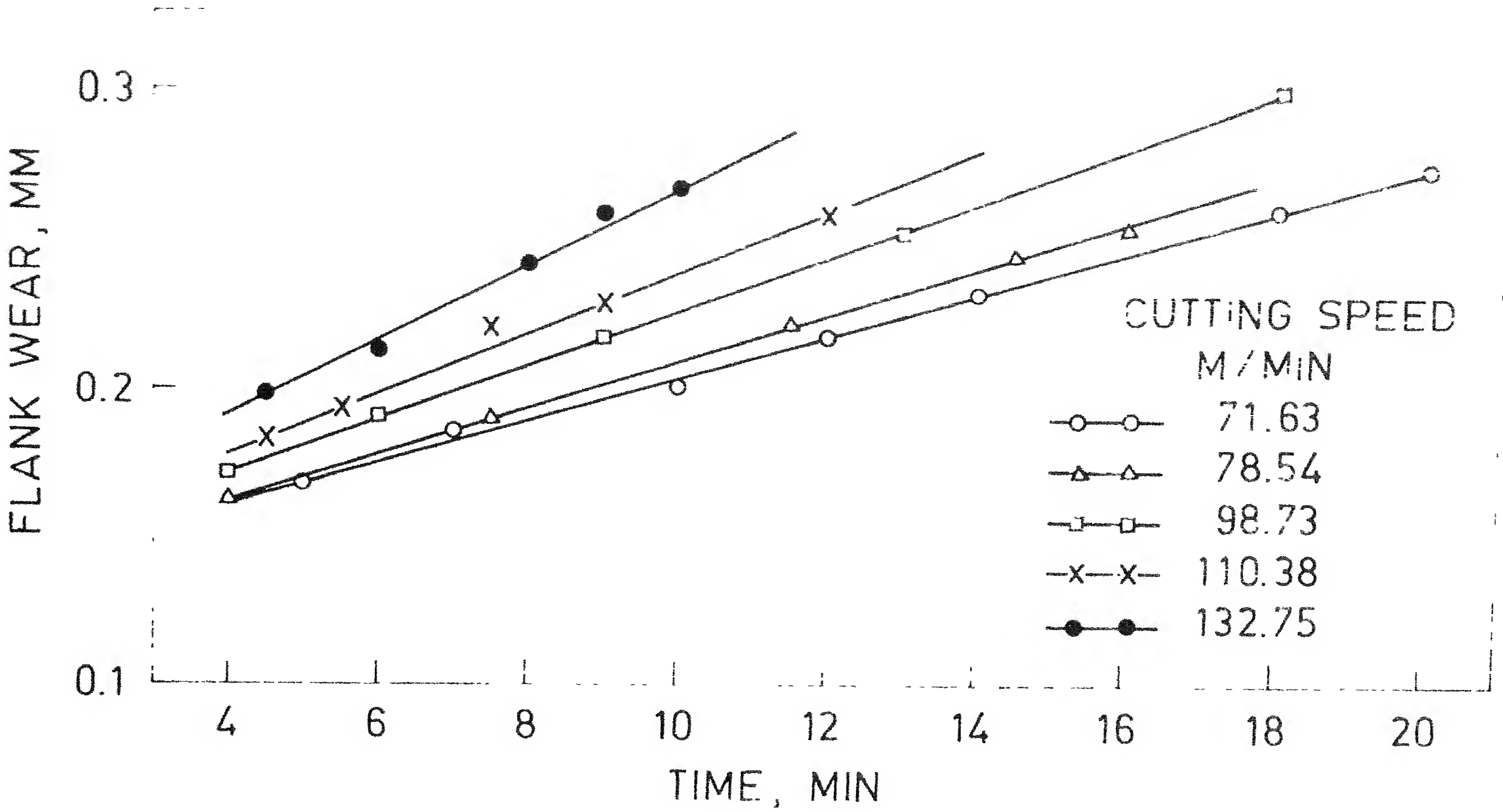

FIG. 15 VARIATION OF FLANK WEAR WITH TIME AT 100 AMPS.

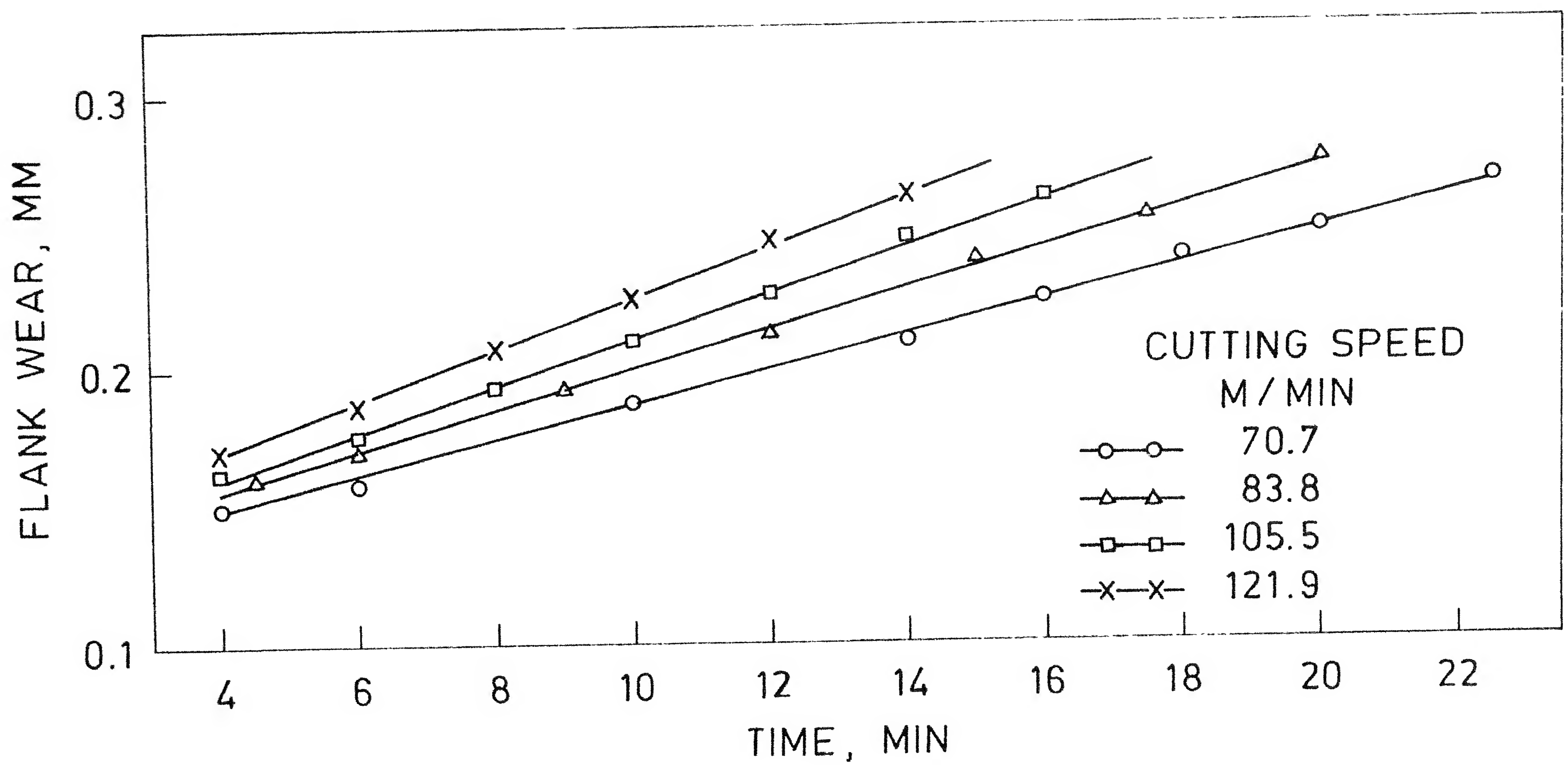

FIG. 16 VARIATION OF FLANK WEAR WITH TIME AT 150 AMPS.

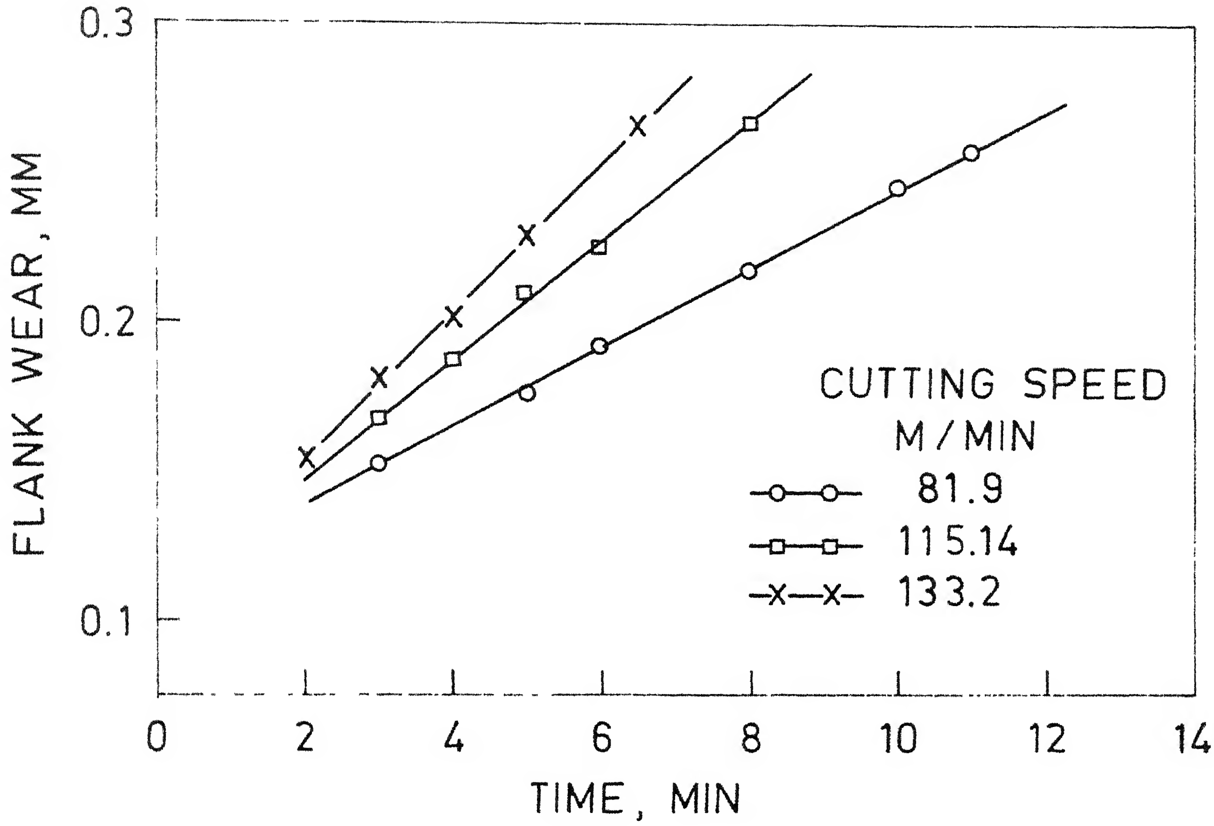

FIG. 17 VARIATION OF FLANK WEAR WITH TIME AT 200 AMPS.

is found from Figs. 14 to 17.

Fig. 18 shows the variation of the tool life with cutting speed on a logarithmic scale. While machining with zero current the tool life variation with cutting speed is found to be linear. This trend is slightly changed in hot machining. The tool life decreases at a higher rate for speeds greater than 120 m/min. Although the cutting forces decrease with increase in heating current, the increase in temperature at the tool tip for higher cutting speeds dominates in its effect to decrease tool life. The increase in the tool wear rate at speeds greater than 300 ft/min, in hot machining was also observed by Barrow (3).

Figures 19 and 20 are plotted from the information read from Fig. 18. Fig. 19 shows the variation of tool life with current for different cutting speeds. Fig. 20 shows the variation of the ratio of tool life in hot machining (T_H) to tool life at zero current (T_O) with heating current at various speeds. The figure shows that the maximum gain in tool life is obtained for a heating current of 150 amperes in the range of cutting speeds of 110 to 120 m/min. For the optimum heating current the tool life ratio is 2.66. The tool life ratio is found to be lower at lower heating currents which is due to

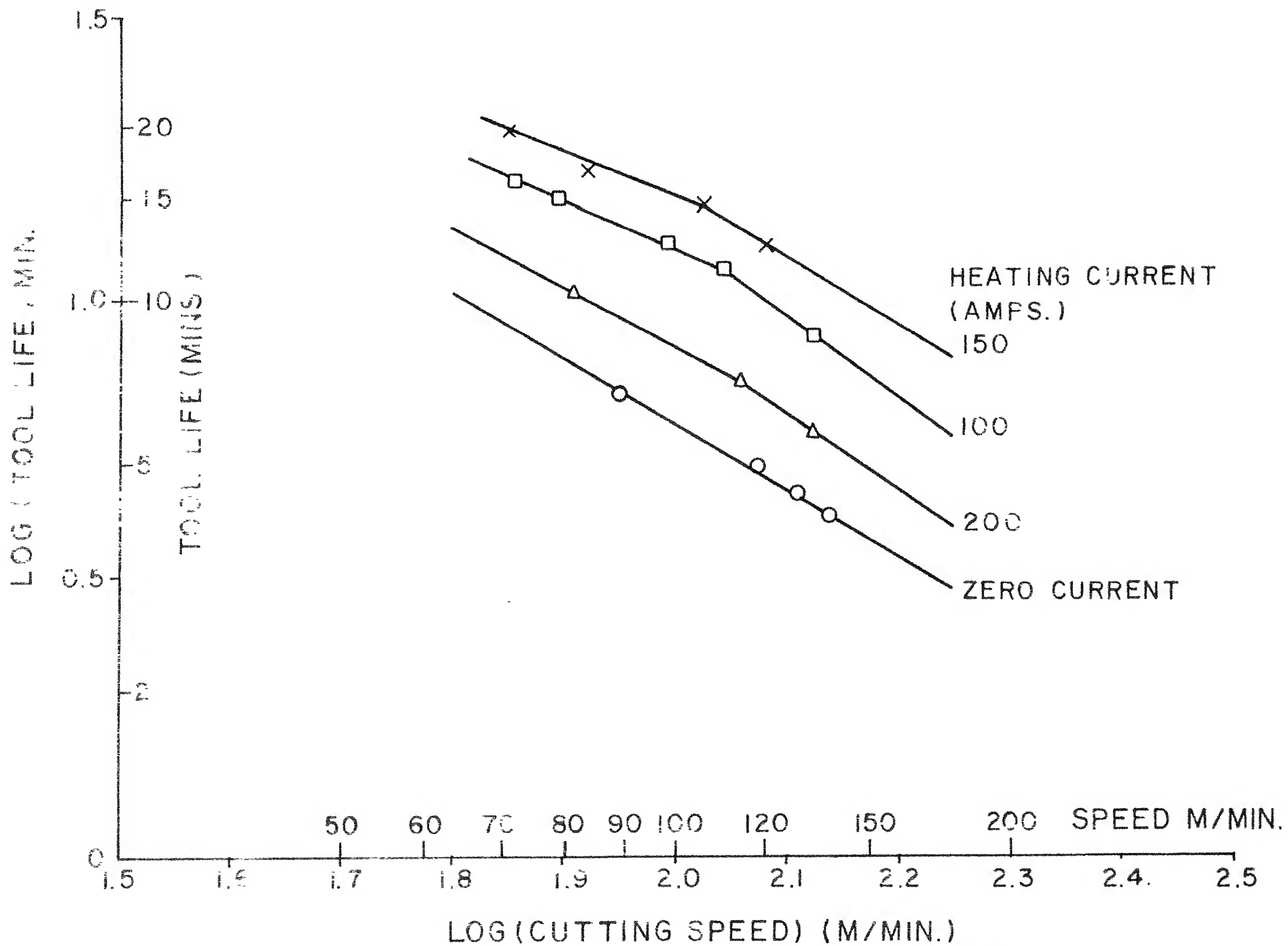

FIG.18 TOOL LIFE VERSUS CUTTING SPEED

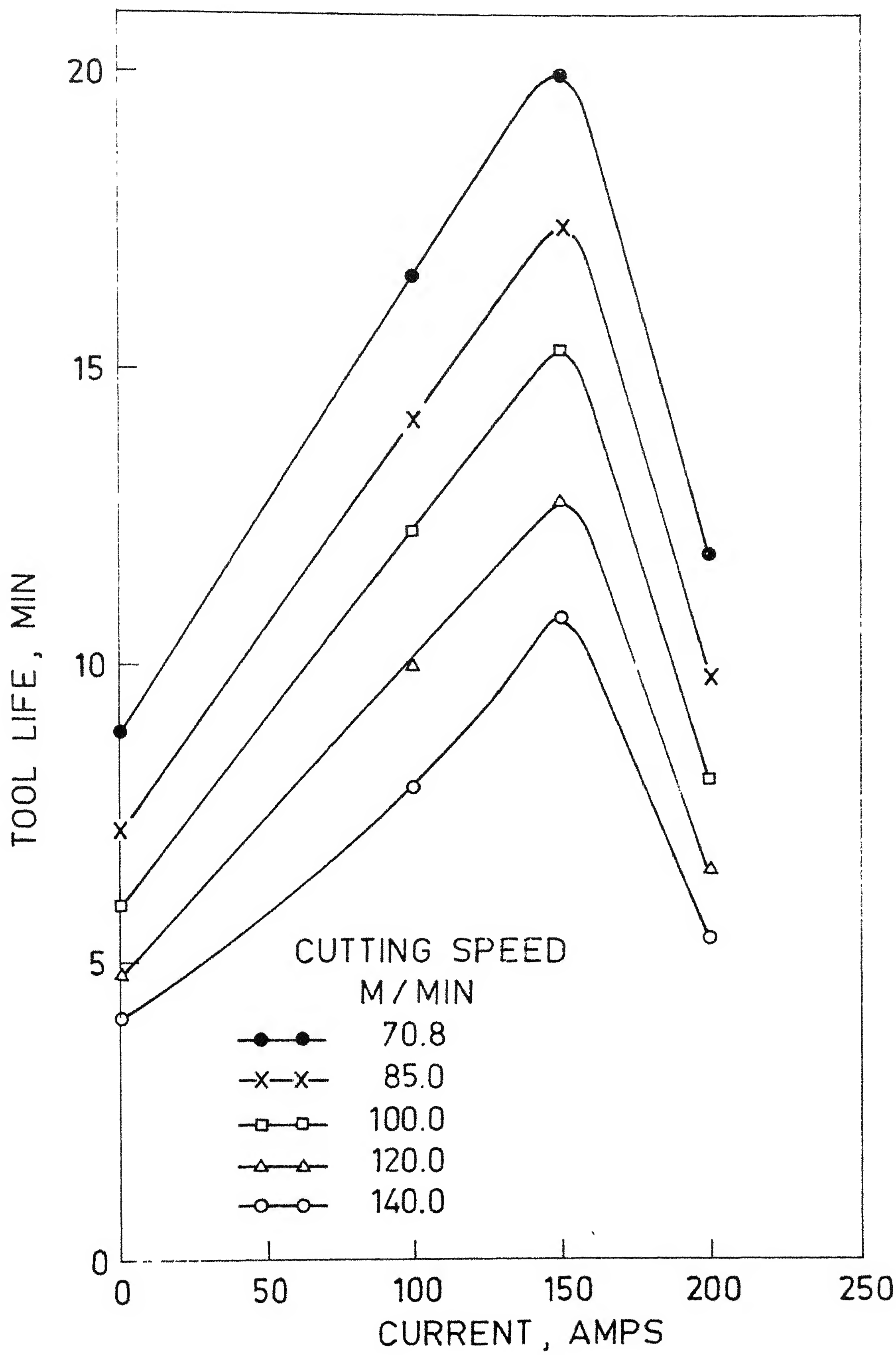

FIG. 19 VARIATION OF TOOL LIFE WITH CURRENT

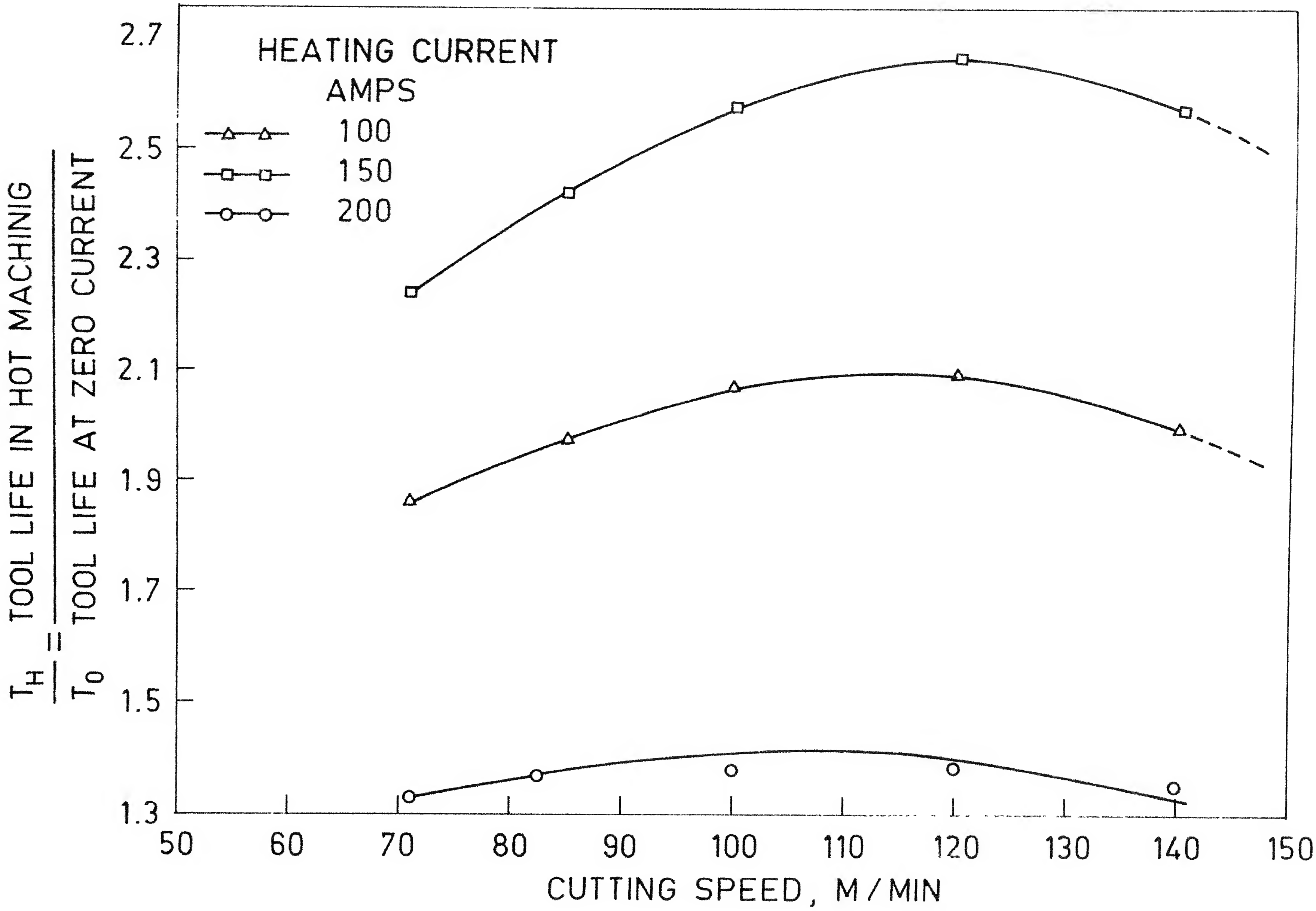

FIG. 20 VARIATION OF TOOL LIFE RATIO WITH CUTTING SPEED.

the fact that the cutting forces are higher at lower heating currents which result in greater tool wear. At higher heating currents, although there is a decrease in the cutting forces, the higher tool tip temperatures assume greater importance resulting in increased wear.

4.3 Variation of Cutting Forces and Surface Roughness with Flank Wear :

Figs. 21 to 24 show the variation of the cutting forces and surface roughness with wear land for constant heating currents of 0,100, 150 and 200 amperes at different speeds. The cutting forces and the surface roughness are found to increase with wear as expected. The increase in the tangential cutting force is between 6 to 10 percent whereas the increase in feed force is 5 to 13 percent with wear. The surface roughness increase is between 20 to 85 percent.

4.4 Variation of Tool Life With Temperature :

Fig. 25 shows the variation of temperature with cutting speed for different heating currents. The variation in temperature with cutting speed is found to be linear, the rate of increase of temperature being lower at higher heating currents. The rate of increase in temperature

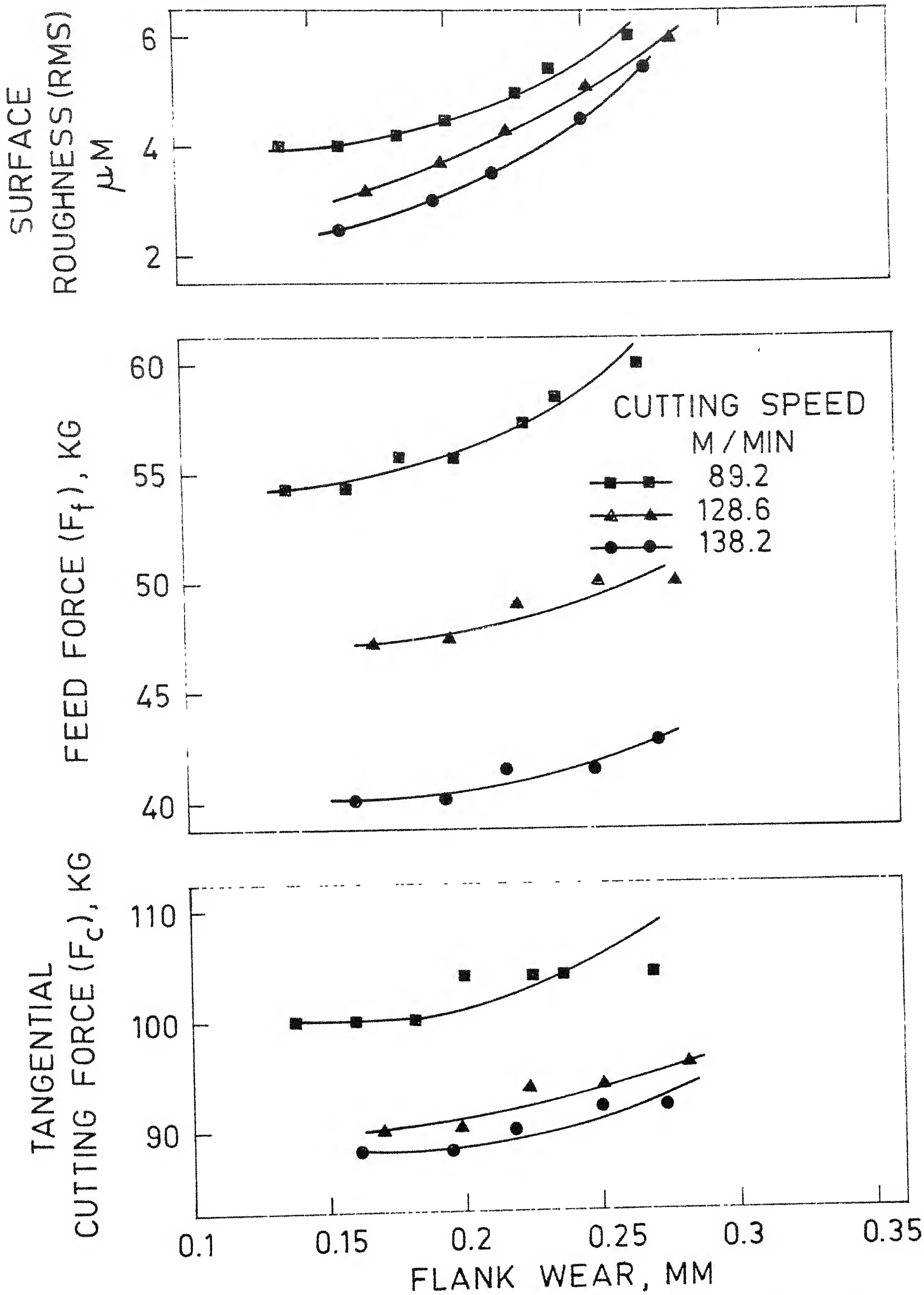

FIG. 21 VARIATION OF F_c, F_f AND SURFACE ROUGHNESS WITH FLANK WEAR AT ZERO AMP.

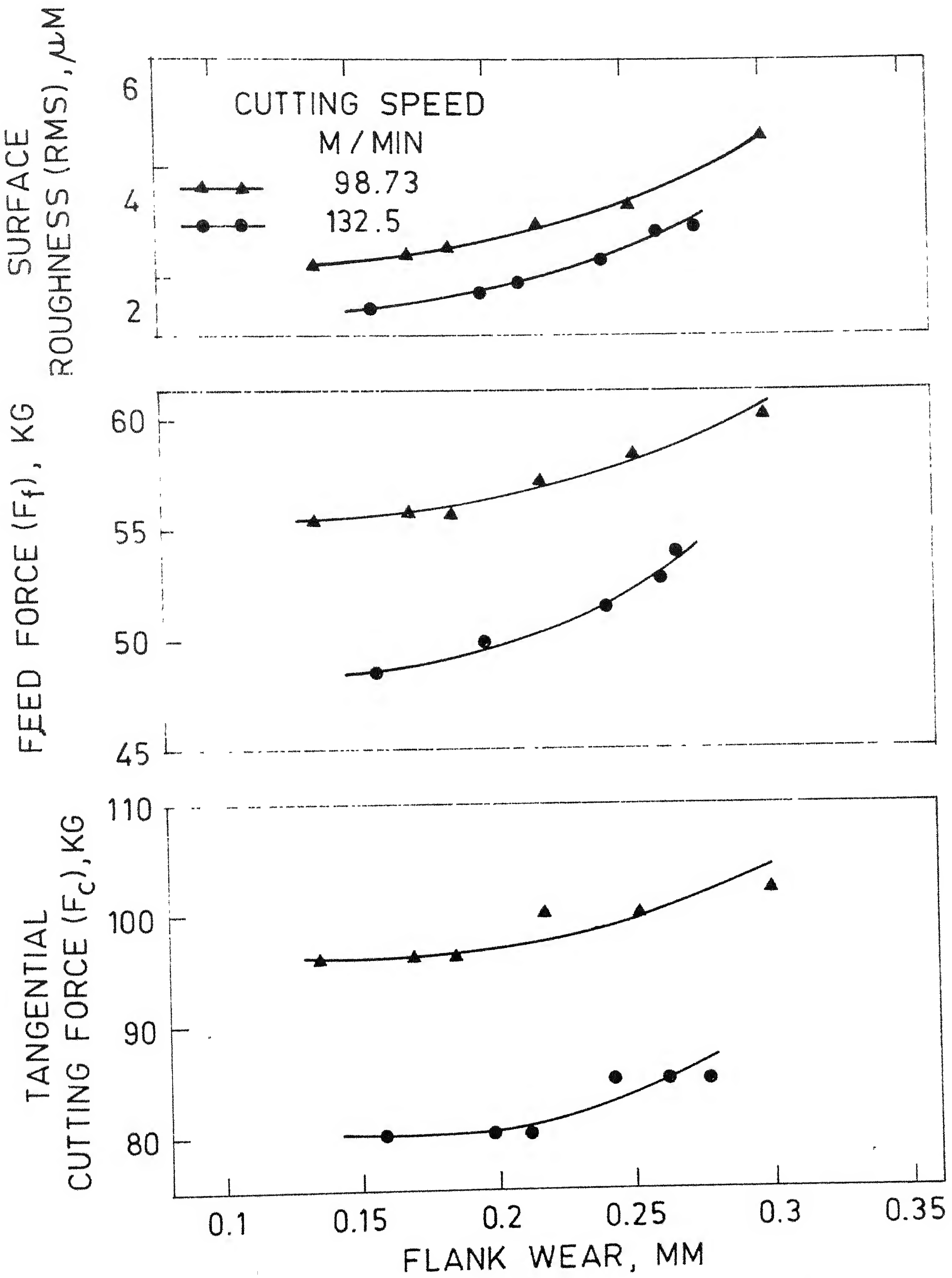

FIG. 22 VARIATION OF F_c, F_f AND SURFACE ROUGHNESS WITH FLANK WEAR AT 100 AMP.

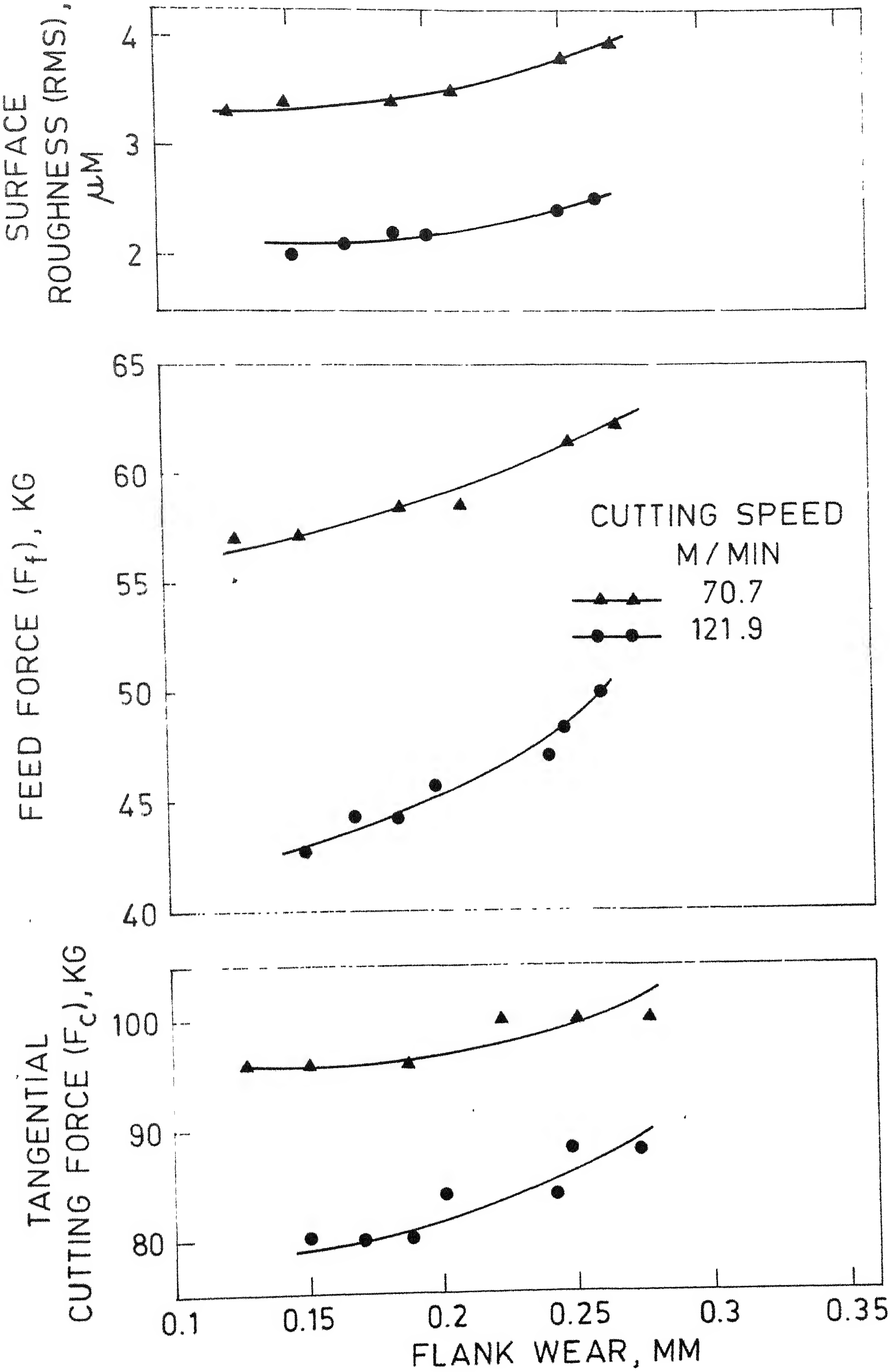

FIG. 23 VARIATION OF F_c, F_f AND SURFACE ROUGHNESS WITH FLANK WEAR AT 150 AMP.

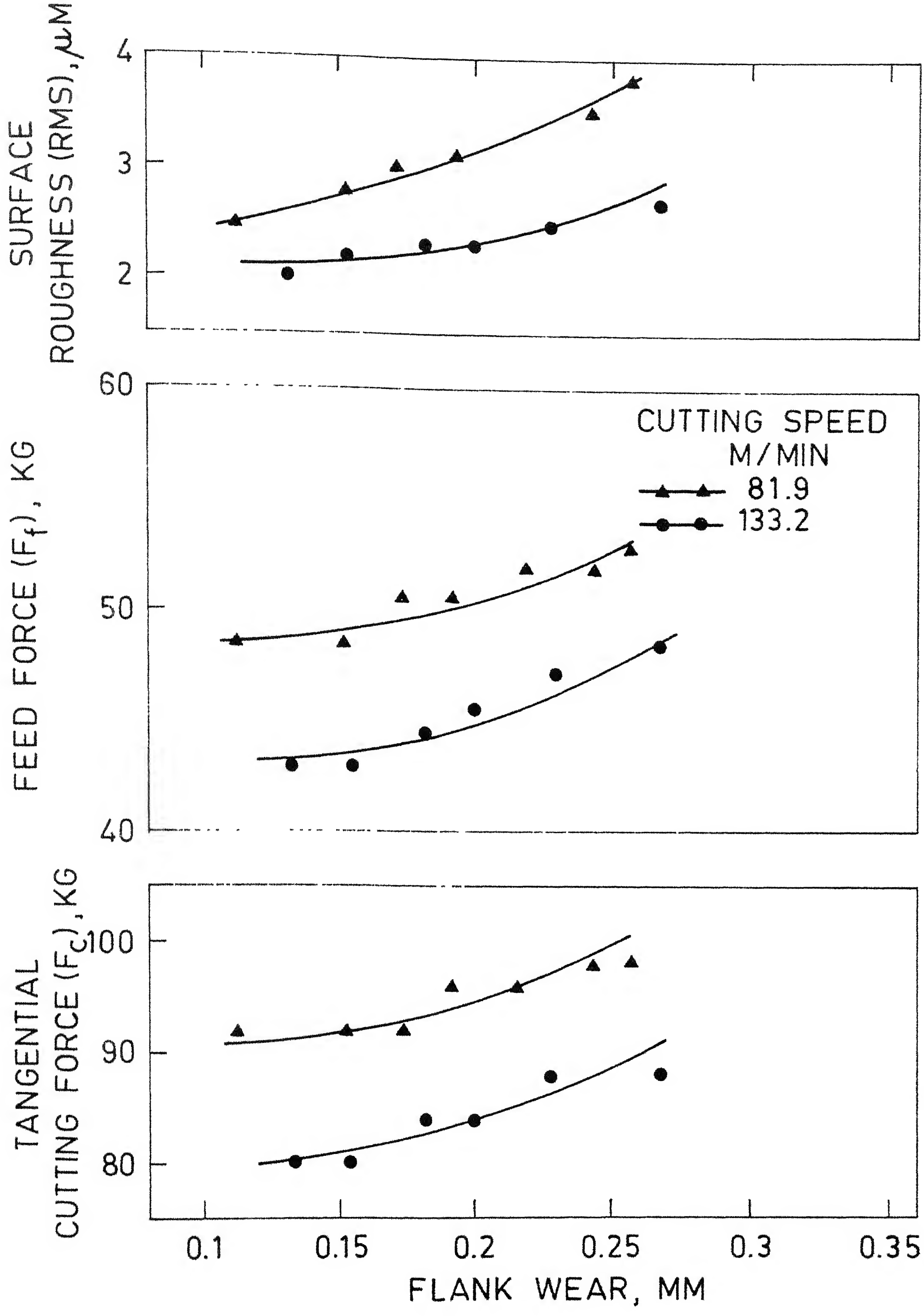

FIG. 24 VARIATION OF F_c, F_f AND SURFACE ROUGHNESS WITH FLANK WEAR AT 200 AMP.

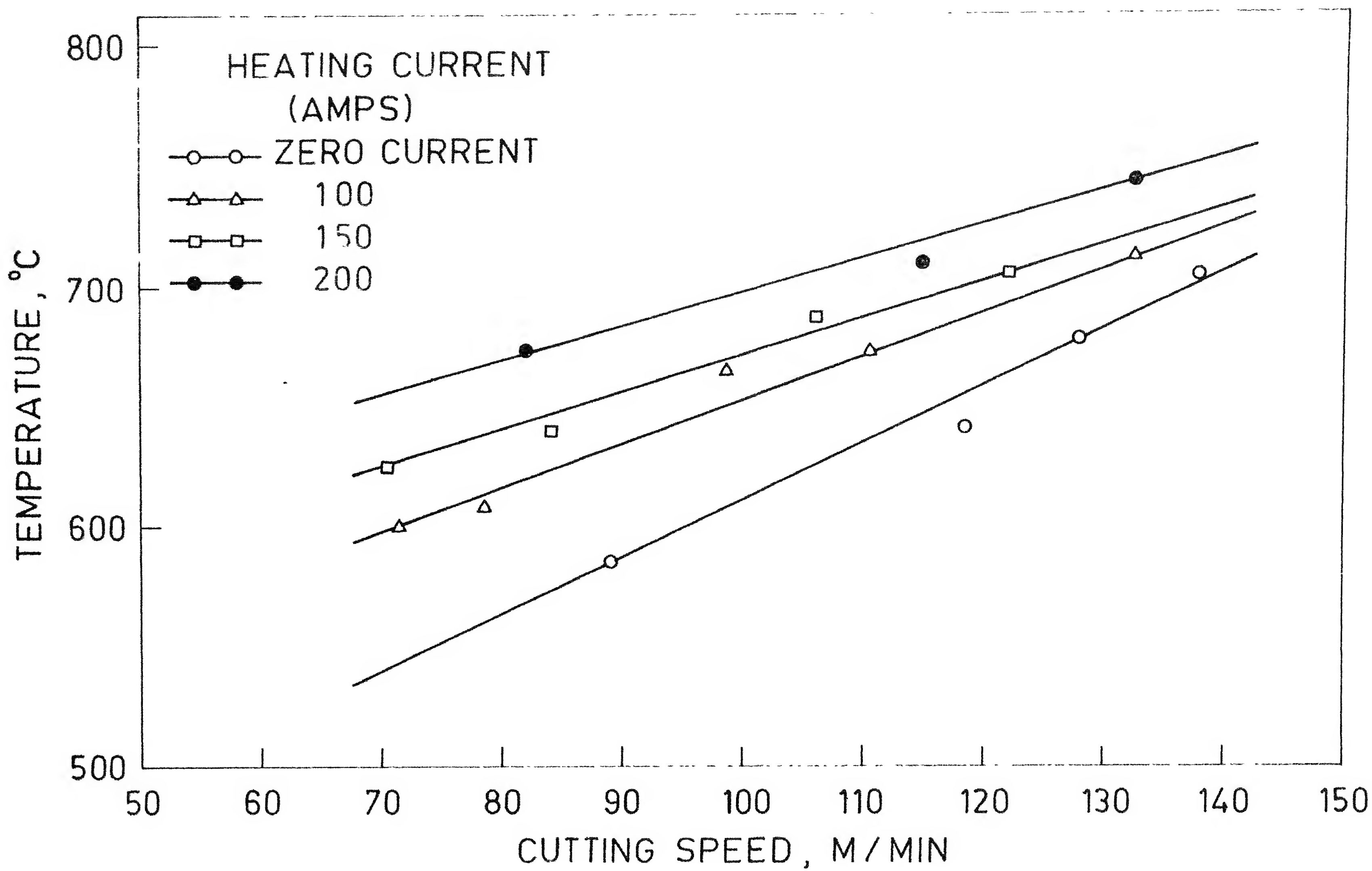

FIG. 25 TEMPERATURE VERSUS CUTTING SPEED AT VARIOUS CURRENTS.

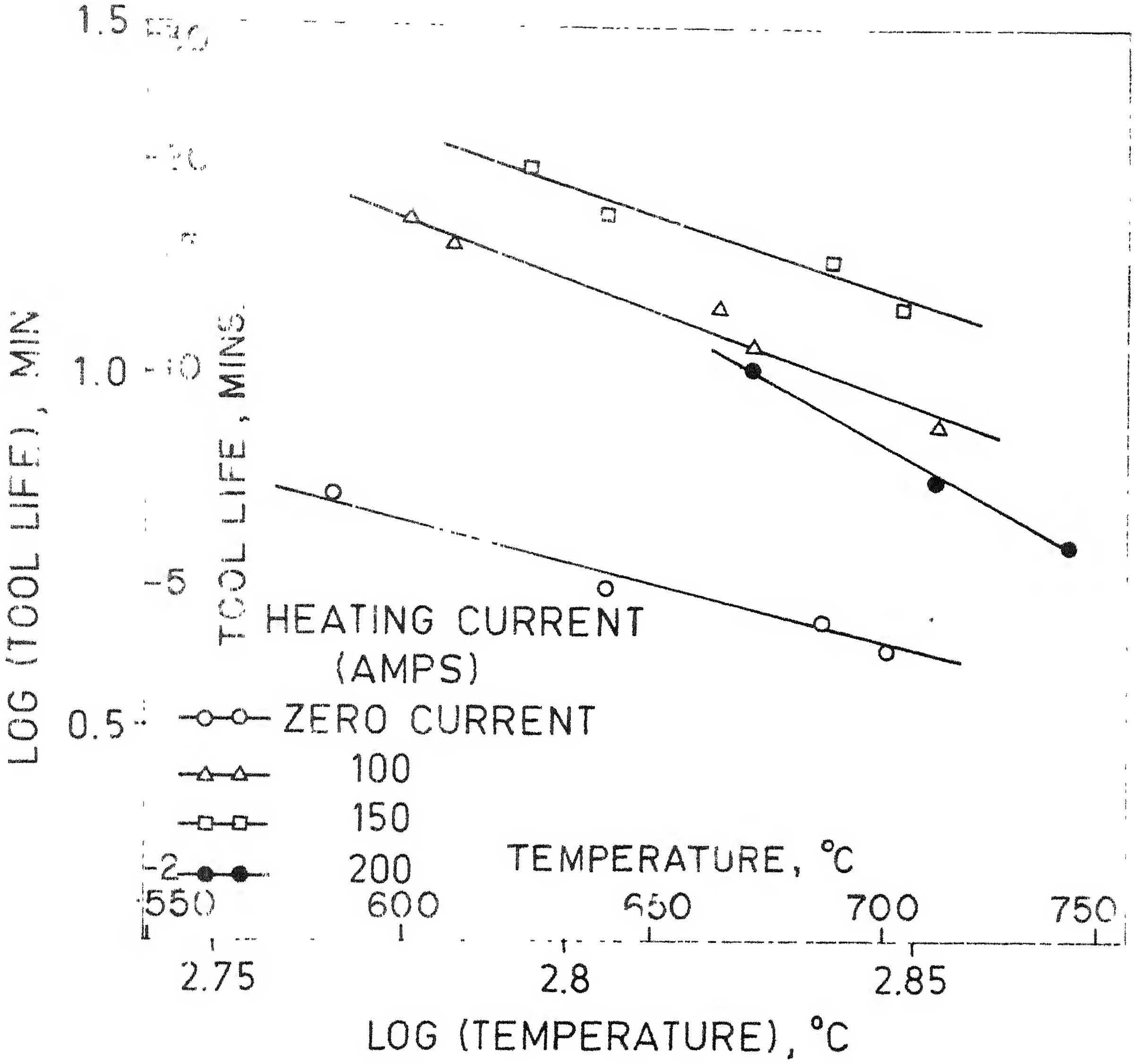

FIG. 26 TOOL LIFE VERSUS TEMPERATURE AT VARIOUS CURRENTS.

decreases while cutting at higher currents due to the larger decrease in the shear strength of the material.

Fig. 26 shows the variation of the tool life with temperature on a logarithmic scale. The tool life decreases logrithmically with increase in temperature. The tool-life temperature relationship for a heating current can be written as :

$$\theta T^m = C_t$$

where θ = temperature, °C

T = tool life, min

and m and C_t = constants

The values of m and C_t for various heating currents are given in the table below :

Heating Current	m	C_t
Zero Current	0.387	1216.4
100 amps	0.279	1313.97
150 amps	0.306	1546
200 amps	0.145	955.46

The results show that the rate of fall of tool life with increase in temperature is much higher at 200 amps. indicating an optimum value of heating current of about 150 amps. An average value of m, upto the range of heating current of 150 amps is found to be 0.324. The value of C_t varies with heating current.

CHAPTER - 5

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 Conclusions :

From the experimental investigation presented the following conclusions are drawn which hold good for hot machining of En-24 steel with Coromant Carbide tips.

1. The cutting forces and surface roughness decrease with increase in heating current. The decrease in the tangential cutting force is between 15 to 22 percent while the decrease in feed force is 10 to 17 percent with heating current upto 300 Amps. At lower speeds the improvements in surface finish is considerable than that at higher speeds.

2. The optimum value of heating current for maximum tool life is 150 amperes in the range of cutting speed of 110 to 120 m/min.

3. The cutting forces and surface roughness increase with wear for all values of heating current at different speeds. The increase in tangential cutting force is between 6 to 10 percent and the increase in feed force is between 5 to 13 percent. The increase in surface roughness with flank wear land is between 20 to 85 percent.

4. The tool life decreases logrithmically with increase in the temperature. The average value of m for the tool life temperature relationship $\theta T^m = C_t$, upto an optimum heating current of 150 amp, is found to be 0.324. The value of the constant C_t varies with heating current.

5.2 Suggestion for Future Work :

It is observed that sparking at the tool tip occurs when engaging or disengaging the tool while an electric current is flowing which causes damage to the tool tip. In the present investigation precaution is taken to avoid sparking by switching on the current immediately after engagement and switching it off just before disengagement of the tool from the workpiece. In future, to carry out investigation in hot machining a simple relay system can be designed (3) to avoid sparking during engagement and disengagement of the workpiece.

It will be interesting to carry out investigation of hot machining on strain hardening manganese steel.

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